SANITARY ENGINEERING

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A PRACTICAL TREATISE

ON THE

COLLECTION, REMOVAL AND FINAL DISPOSAL OF

SEWAGE AND HOUSE REFUSE

AND

THE DESIGN & CONSTRUCTION OF WORKS OF

DRAINAGE AND SEWERAGE

WITH

NUMEROUS HYDRAULIC TABLES, FORMULÆ & MEMORANDA

INCLUDING AN EXTENSIVE SERIES OF

TABLES OF VELOCITY & DISCHARGE OF PIPES & SEWERS

BY

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THIRD EDITION, REVISED AND IN PART RE-WRITTEN

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IN TWO VOLUMES—

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SEWAGE DISPOSAL, REFUSE DESTRUCTORS,
TRADE EFFLUENTS AND SEWAGE FUNGUS.

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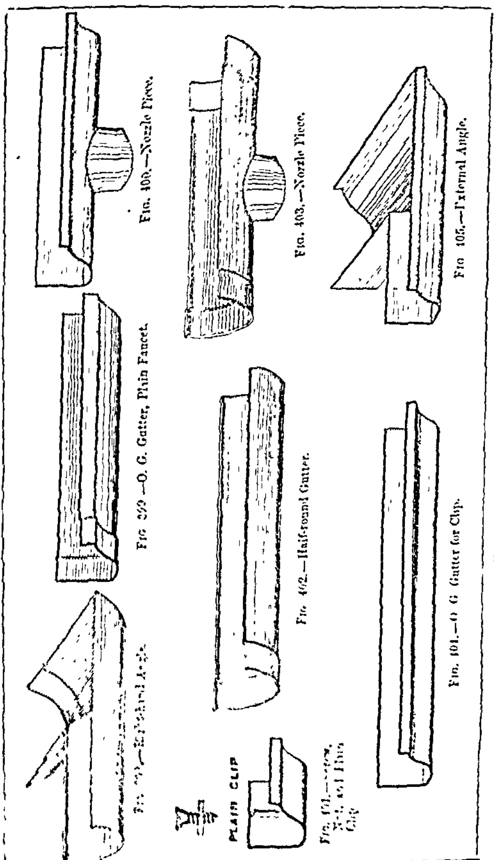

Fig. 398.—External Angle.

Fig. 399.—O. G. Gutter, Plain Faucet.

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Fig. 403.—Nozzle Piece.

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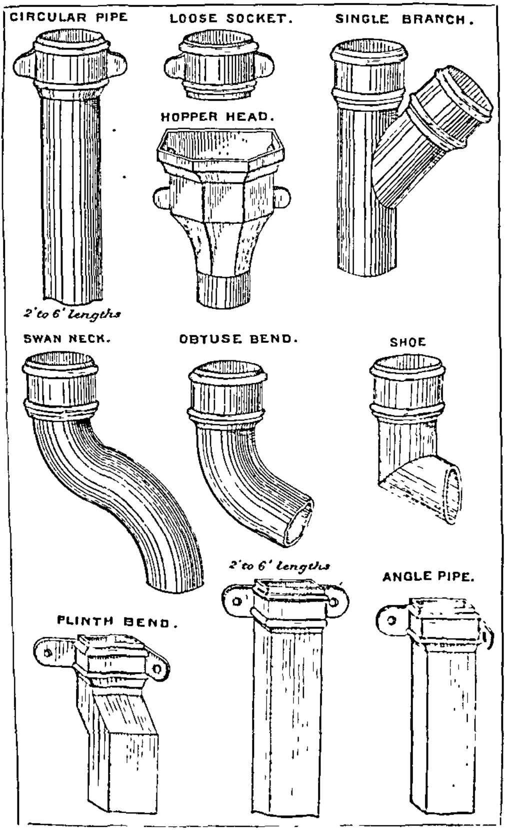
Fig. 405.—External Angle.

Figs. 398—405.—Eaves' Gutters.



Figs. 406—415.—Rainwater Pipes.

From Roads.—Surface-water from roads, parades, and pavements is collected by giving a fall or current to the surface, and by forming surface channels in paving, concrete, asphalte, etc.; tar paving is also much used for this purpose in many towns.

Surface Gutters, Fall of.—Surface gutters should have a fall of 1½ inches in 10 feet, or 1 in 80, though the fall is sometimes as little as 1 in 125.

Surface of Road.—The surface of a road should have a fall towards the side channels of from 1 in 20 to 1 in 40.

Drains.—As the water thus collected would at times accumulate into a considerable stream, besides being liable to get dammed up and overflow the channels, if kept on the surface, it passes at intervals through gratings into underground drains, which carry it off to some outlet.

Distance Apart of Gullies.—The following table gives the distance apart at which street gullies are placed in Leeds :—

TABLE 94

Inclination of Street	Distance Apart of Gullies
1 in 1,000	60 yards
1 in 500	40 "
1 in 400	37½ "
1 in 300	35 "
1 in 200	32½ "
1 in 100	30 "
1 in 75	27½ "
1 in 50	25 "
1 in 25	22½ "
1 in 10	20 "

Catch-pits.—As a good deal of sand and dirt is washed off roads and open spaces by the surface-water, a catch-pit should be formed underneath the grating, in which the silt may be deposited, and from which it can be readily removed on raising the grating or other cover, which should be hinged for this purpose.

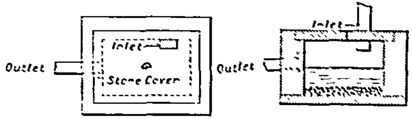
The following are the requirements which should be kept in view in selecting the kind of catch-pit, or gully, to be used to suit any system of drainage :—

(1.) It should have sufficient area to carry off all the water led to them.

(2.) It should not be easily choked on the surface by leaves or other *débris*.

(3.) It should be sufficiently large to retain all sand or road detritus, and prevent it being washed into the drain-pipe.

(4.) The grating should be amply strong to resist any traffic that may come upon it.



Plan. Section

FIG. 416.—Catch pit for Surface Water.

(5.) It should give the least possible obstruction to traffic.

(6.) It should be made in such a manner as to be readily cleaned out.

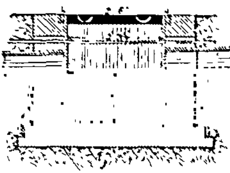
(7.) The drain from it should be easily freed from any obstruction.

(8.) If used in connection with a sewer, it should be trapped, the water seal being 4 inches deep, to prevent escape of sewer-gas.

The catch-pit may be built of brickwork in cement 4½ or 9 inches thick, or formed in stoneware, and vary in size according to the requirements of the situation.

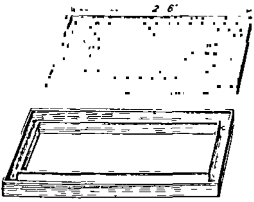
If made of brickwork, it

SECTION A-B



Sand Check which allows of ventilation of drain thro Catchpit

FIG. 417



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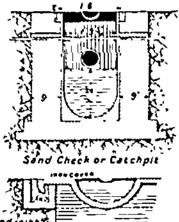


Sand Check or Catchpit

Section of Cover showing Sand joint

FIG. 418. FIG. 419

should be rendered in cement on the inner faces; a stoneware junction pipe set on end will often answer the purpose.

The bottom should be formed of concrete or a 2-inch York flag, extending underneath the sides. From this catch-pit the water is carried off by stoneware drain-pipes, the outlet being from six inches to three feet above the bottom.

Separate System.—Under this system, traps for surface water are not required, and it is only necessary to collect the silt, leaves, etc., in a catchpit, so as to prevent them from entering and choking the drain.

The catch-pit in Fig. 416 is intended to arrest the passage into the drain of leaves and dirt from the roof of a building.

The slab of stone protects the drain from being improperly used by slops being poured into it, which might be the case if the stone was replaced by an iron grating.

The cover should be capable of being readily removed for the purpose of clearing out the accumulation in the catch-pit.

The catch-pit shown in Figs. 417—419 is intended for use on a line of drain to intercept road detritus, etc., during a freshet. Sewage should never be allowed to flow through such catch-pits.

Mason's, or dip traps, are sometimes used for surface drainage in connection with this system, but are of no value, as the tongue is not required.

Combined System. — The following traps are used as silt collectors on this system.

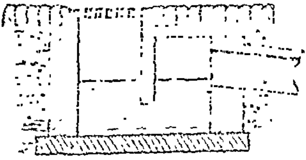


FIG. 420.—Mason's, or Dip Trap.

Mason's, or Dip Traps.—Mason's, or dip traps (Fig. 420), are sometimes used for this purpose, if connected with foul drains, but they are objectionable, as the point at the joint of the tongue is seldom sound, so that sewer-gas is emitted.

Lowe's.—Lowe's patent trap has been extensively used by the War Department. It is strongly made, and has a hinged grating, so that it can readily be opened and cleared out. The seal, however, rarely exceeds ¾ inch, even with the largest size, whilst it very often has practically no seal at all, and it would therefore be advisable to use this trap only in connection with the separate system. Owing to very shallow water level this gully is soon frozen up, and is not to be recommended.

Fig. 421 shows Stone's improved Lowe's traps; in this description the seal is much improved.

access for cleaning is provided by a screw-plugged inspection eye. The trap is manufactured by the Albion Clay Co., in "granitic stoneware."

The "Accomo" (Fig. 16, Plate XLIII.), a patent adaptable yard gully for board schools and other large areas, is also made by the Albion Clay Co. The advantages claimed for it are as follows:—The outlet of the gully can be raised or lowered to suit any fall of drain. The middle and top pieces are made in various heights, both plain and with side inlets to take any size connection at any level. The middle pieces are made cylindrical, enabling the side inlet sockets to be turned in any direction to receive drain connections without disturbing the position of the outlet; the middle and top pieces being made to turn round independently, provide greater facility for making the connections in straight lines and dispensing with bends, which are generally necessary when the old form of gully in one piece is used—it being unadaptable. Two middle pieces can also be superposed, with inlets on each if required, the lower one to receive a long drain with deep fall, and the top one a shorter drain with less gradient. By this means also the inlets can be raised or lowered so that the connections can be made to pass over or under any obstacle. The top pieces are made square at the top to receive a square grating, and the bottom part of same is made cylindrical, enabling it to be turned round for the accommodation of

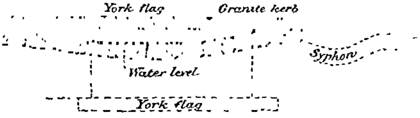


FIG. 424.—"Buddle Hole."

the required position of grating, dispensing with brickwork and cement rendering, which is necessary with the ordinary round-top gullies.

Stokes' Gully Trap.—This trap (Fig. 14, Plate XLIII.) has been designed to provide a ready means of access to the outer side of the trap, so as to clear the drain beyond. It is made by Messrs. Bailey & Co.

Sykes' Patent Yard Gully is shown in Fig. 15; it is made by the Albion Clay Co., Ltd. The advantages claimed for it are, that it possesses a large grate area to take away storm water, with a small surface exposed to evaporation; its great depth of water seal prevents it becoming untrapped during the hottest weather, its outlet is arranged so as to discharge over a sharp arris, which prevents lodgments of leaves and straw. The gully is provided with an inspection hole fitted with a screw-plug for the purpose of readily clearing the drain. These gullies

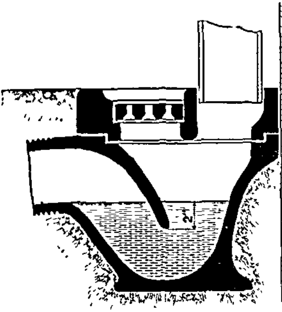


FIG. 6—Ducketts' Improved Rain-Water Gully.

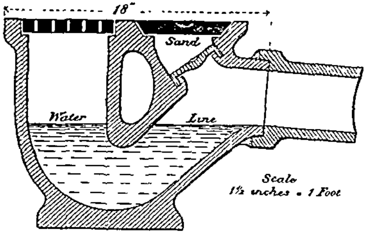


FIG 14.—Stokes' Gully Trap

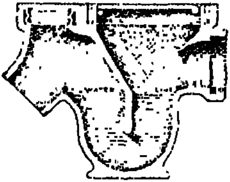


FIG 15—Syke's Patent Yard Gully

can be obtained with back or side inlets, or with vertical back inlets to receive rainwater pipes.

There are a great many other traps to be recommended by Clarke, Carlisle, and others.

Buddle Hole.—A "buddle-hole" (Fig. 124) is an opening under a kerb, and is advantageous, as it gives a free and undisturbed water-way, and avoids the necessity for a grating in the street itself.

Brown's "Victor" Gully (Fig. 125) is a combined gully and buddle hole. This gully has an ample trap, is provided with an opening for

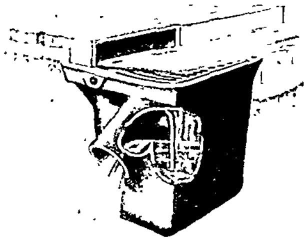


FIG 425 —Brown's "Victor" Gully

drain inspection, it has a large storage capacity, and is provided with a storm weir, so constructed and arranged that the overflow readily comes into action, and so prevents the flooding of the roadway. The gullies can be had wholly in cast iron; or, the tank may be in stoneware, and the grate, frame and weir in iron.

Liable to become unsealed.—The whole of these traps for letting surface water into a foul drain are sure to become unsealed with any continuance of dry weather, and the only way to prevent it is to send a water-cart round periodically to flush and refill the traps.

A great deal can be done in this way by the judicious application of some small but constant supply of water as from a pump, but, of course, this cannot be applied on any large scale.

CHAPTER XIII.

SUBSOIL DRAINAGE.

Source of Moisture.—The principal source of moisture in the soil is rain, and it is only when in excess, so as to become stagnant by retention within a foot or two of the surface, that it becomes injurious. Rain is in itself a source of fertility, but stagnant water is prejudicial, and its removal to a greater depth is desirable.

Injurious Effects of Wet Soils.—Wet soils which retain moisture injure vegetation, in consequence of the extreme reduction of temperature involved by evaporation, and the roots also are damaged by standing in water. If the soil is saturated the warmth of the air cannot penetrate into it, as heat does not descend in water. Wet soil also prevents the circulation of rainwater through the soil, which would be a benefit to vegetation. Wet soils produce a considerable reduction in the temperature of the atmosphere, and are very often the cause of fogs, and such land, when used as the site for habitations, is injurious to health.

Peat and heavy clay shrink about one-fifth their bulk in drying, and swell again in wet weather, so that a building resting on such a foundation is liable to serious injury if not carried below the reach of atmospheric changes.

Subsoil drainage is thus often required to improve the value of land and to secure the stability of a building; in many places also it is a matter of importance on sanitary grounds.

The General Report of the Commission on Improving the Sanitary Condition of Barracks and Hospitals lays down, at p. 58, the following principles with reference to sites for barracks:—

"Having selected the site, the whole area within the barrack enclosure should be thoroughly under-drained to the depth of four feet at least, by tile drains placed at distances differing according to the nature of the subsoil and the fall of the ground. The lines of drainage should be closer to each other, or more distant, according as the subsoil is more or less retentive of moisture. In some positions, with a very porous subsoil, in which water never remains, tile drainage may be unnecessary,

but such instances are rare exceptions. The drainage should be, in all cases, sufficient to keep the parade ground firm and dry." And with reference to sites for barrack huts, at p. 171, it is stated that "A dry subsoil is, in fact, absolutely necessary to health."

The necessity for artificial drainage does not so much depend on the rainfall, or the power of the sun to carry the moisture off by evaporation, as upon the character of the subsoil.

If the subsoil is composed of sand or gravel, or of other porous earth, the greater part passes off by natural drainage below the surface. If, however, the subsoil be of clay, rock, or other impervious substances, the downward flow of the water is arrested, and it sometimes shows its presence in the form of springs. All wet soils may be divided into three classes. 1st. Free soils, from which the water is gradually discharged by percolation through itself, by evaporation on the surface, and absorption by vegetation. 2nd. Peaty soils, which allow the water to percolate, but not so readily as free soils. They have great powers of capillary action, so that a large proportion of water, after being absorbed, is given off by evaporation. 3rd. Clay soils, which are retentive of all the water they absorb until it is relieved by evaporation or vegetation.

Other descriptions of land vary between these classes in proportion to the amount of clay in their composition and their capacity for natural drainage. Each variety requires special treatment for removing the subsoil water, and this is especially the case with retentive clay soils, which are so powerfully acted on by the atmosphere.

The first of these two classes owe, from their nature, their wetness simply to position, and all that is required is to afford an outlet for the water, so as to set it in motion, and thus lower the subsoil water-levels. In the case of high and dry lands, it sinks beyond the reach of evaporation, but it still remains within the reach of atmospheric influence in the case of drained lands, even though it thus stands at a lower level than it otherwise would.

Clays require very careful treatment, on account of their retentive character and capabilities of expansion and absorption. Subsoil drainage makes them permeable, though when the surface is not properly and deeply cultivated their capabilities of absorption are limited, and those of retention and expansion cause them to resist the admission of the rainfall.

Clays readily discharge the excess of water, after a heavy downfall, after their own capacity for retention is satisfied; on other occasions they give it out gradually.

The retentive nature of clay soils can only be restrained by complete aëration. The drains should exert a powerful influence on the intermediate mass of soil, so as to secure a quick and uniform passage through it for the superabundant water.

Clay is capable of absorbing from 10 to 70 per cent. of its own weight of water.

It should be remembered that drainage of clay soils only alters their condition, and not their constitution. The constant expansion and contraction, as water is absorbed and given off, as well as the retentive power of clay soils, form a marked distinction between them and free soils.

Clay cracks as it dries. It also contains fissures of sand and gravel, and where deep cultivation breaks up the surface, the water finds its way into the clay by these various channels, and thence into the subsoil drains. Atmospheric air follows the water, and as the sides of the cracks are gradually coated with soil carried down by the water, the sides are prevented from sticking together again. The disintegration of the clay soil and the multiplicity of these fissures become greater every year, and consequently the subsoil drainage more effective, as well as capillary attraction to the surface. There is thus evidently a depth suited to each soil to which it is desirable to reduce the subsoil water-level, and beyond which it would not be safe to go in the case of cultivated lands without unduly testing its power of supplying moisture to the plants by capillary action.

Depth of Drains.—The ordinary depth for draining agricultural land and sewage farms is from 3 feet to 4 feet. As a general rule the minor drains are made from 2 feet 9 inches to 3 feet 6 inches, and the mains from 3 feet 3 inches to 4 feet deep. They should be properly executed and so arranged as to secure complete aëration of the subsoil between them, so that although the individual particles of the soil may be moist, it will not retain water.

Many authorities recommend deeper drainage than this, and it is an established fact that the deepest drains flow first and longest. It may be remarked here that in the case of cultivated land, as the surface is never uniform, drains four feet in depth may approach in some places within three feet of the surface, and thus the subsoil water is not kept sufficiently low, and in addition to this, if only three-foot drains are used in the first instance, they may for the same reason come dangerously near the surface, and be disturbed in the operations of cultivation. This would not apply with the same force in the case of subsoil drainage for sites of buildings. Under the latter circumstances it may in some instances be necessary, in order to obtain a fall for the drains, to make them only two feet deep in places. They should then be placed at only about half the intervals at which four-foot drains would be laid.

The contention for shallow drains is really maintained by the question of expense, as the extra foot in depth involves an additional foot of excavation at the top, and is not a mere prolongation of the thin end. The earth also gets harder the deeper we go.

Mains should be placed from three to six inches lower than the minor drains discharging into them, so as to avoid any obstruction which might cause the water to head up into them.

Arrangement of Drains.—It is necessary, in the first place, to ascertain *the source of the injurious water, so as to secure a permanent and* effective discharge. To do this, the geological formation and dip of the strata should be considered. In some cases, the moisture is due to pervious strata cropping out just over an impervious one, and even underlying it, in which cases, by the judicious use of the auger, or boring tool, to tap the water-bearing strata, in connection with other drainage operations, large tracts of land have been cheaply and effectively drained, with beneficial results, extending to some distance around. This is known as Elkington's system. Numerous test-holes should, under any circumstances, be made to ascertain at what depth below the surface the water will lie in wet seasons. The natural drainage by hollows and valleys should be studied and retained as the proper course of drainage, though the future conduit is to be below the surface. Close attention must also be paid to the variation in the inclination of the surface, as well as in the nature of the soil. Relief drains should be applied at all changes of planes to those of smaller inclination, so as to avoid the impediment caused by the slower flow of the flatter drains.

It is thus seldom that the drains can be laid uniformly parallel to each other, but they must be arranged to suit each portion of the ground. The minor drains must be of sufficient size to carry the total maximum amount of water that may flow through them without pressure, as otherwise it would wet the land through which it passes without draining it.

The size of the mains should be calculated to carry away readily the water to be collected from the minor drains. In each case proper allowance should be made for the inclination of the pipes.

Fall.—When the general surface of the ground is nearly level, very little fall need be given to the drains. When practicable, it is well to have a fall of not less than 1 in 100; more is preferable, but as little as 1 in 400 is sufficient if the drains be very carefully formed. It will, however, be usually found less expensive to make a fall of 1 in 200 rather than 1 in 400, as the latter requires extra care in forming it. A very steep slope is objectionable, as the flow of water tends to injure or obstruct the drains. With steep slopes it is desirable to place the drains at less intervals than with ordinary slopes. Stone drains require a greater *fall than tile drains, as the water does not pass through them so easily.*

The fall should be uniform, or of increasing descent, towards the outfall, to avoid deposit of silt, as particles which would be carried along the pipes at a good fall might be deposited when the flow of water is

lessened owing to the reduction of the fall in the drain. Where an alteration of fall to a decreasing rate of fall must be made, a silt basin should be placed to catch the deposit.

Distance between Drains.—Under similar conditions the distance apart should be in inverse proportion to the rainfall, so that the maximum amount may be freely absorbed and discharged at all times. In very light land the intervals between the drains may be as much as 20 yards, and the distance may vary from that down to 5 yards for a stiff clay; the distance depending upon the depth of the drain. In porous soils the distance between drains may be 10 to 12 times their depth; in light loams 8 to 10 times; in ordinary loams 6 to 8 times; and in retentive clays 4 to 6 times.

Taking 3 feet as an average depth we get

Porous Soils .	at from 30 to 36	feet intervals.
Light Loams	,, 24 to 30	,, ,,
Loams . .	.. 18 to 24	,, ,,
Clays ..	,, 12 to 18	,, ,,

The intervening ground will then be effectively drained, the level of the water in the ground between being somewhat as indicated in Fig. 426. In gravelly soils, drains may be laid at greater intervals than 10 feet, but they should then be deeper than four feet. In good clean gravel the drains may be dispensed with. In every case, however, due

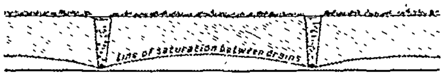


FIG. 426.—Distance between Drains.

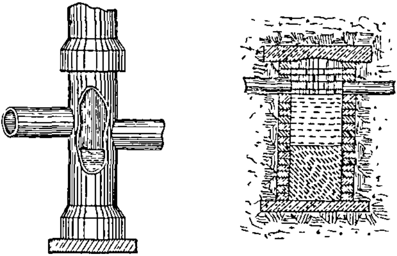
regard must be paid to the continuance of humidity of the atmosphere, and to the character of the soil.

In the case of a steep slope terminating in a flatter one, with soil of the same character, the soakage from the hill will necessitate a greater number of drains on the lower land than on the higher.

Direction.—The minor drains should follow the line of greatest descent, *and it is evident that when laid at right angles to the mains,* and so parallel to each other, the shortest possible drains are obtained in land that admits of uniform drainage. They thus share the work done uniformly. In ploughed land they very often follow the furrows when straight, or nearly so, instead of crossing the ridges, as they should do if the plan of parallel equidistant arrangement were strictly adhered to, and this plan should always be adopted in grass land, unless there is

a probability of its being broken up, flattened, and laid down again. Where drains are laid across the fall of the land, water escapes from them in its passage. If the work stops on a slope, a cross drain, called a header, should be introduced, connecting the tops of all the minor drains, so as to cut off the water passing down the slope in the subsoil between the pipes.

An open drain is useful on a gentle slope to cut off the surface water flowing from the upper portions, and would be more effective than an under drain. Sometimes it is necessary to use both the header and the ditch. The direction of the mains may have to be modified, so as to increase their discharging power if, from motives of economy, it is undesirable to use a larger pipe. With this object in view, two separate



Figs. 427 and 428.—Ordinary forms of Silt Basins.

mains are laid on each side of the hollow, and the inclination increased by running the head of each upwards into the rising ground.

It is objectionable to use long main drains, especially with a low gradient, as they check rapid action in the system. When they cannot be avoided, wells, or sumps, with overflow pipes into some convenient ditch, should be introduced into the line of drain to relieve the pressure.

Outlets.—The outlets should be carefully chosen, and should be as few as possible, consistent with a proper allotment of the lengths of the mains. An average of about 14 acres to one outlet appears to be the usual practice. The outlets should be composed of iron pipes, set in masonry, and discharge with a drop into a watercourse. Care must be taken that the outlets do not get stopped up, and that they are at such a level that there is no probability of water being forced back through them during floods. A flap is sometimes used for this purpose,

as shown in Fig. 3, Plate XLIV., opposite, which gives the details of the work required in connection with outfalls for either a small or large system of drainage. An iron plate, with the date and number on it, should be let into the masonry, and entered on the drainage plan. The site of all the drains should be correctly shown on the plan.

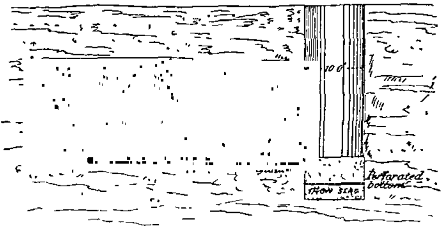


Fig. 429.—Method of Draining the Subsoil Water from the Exterior of the Sewers.

Silt Basin.—Silt basins should be formed on mains at junctions where there is likely to be a great flow of water, or at the foot of an incline in the drain, where there is a change of the fall to one less steep. They may be formed of brickwork, or with a large pipe on end, or with a

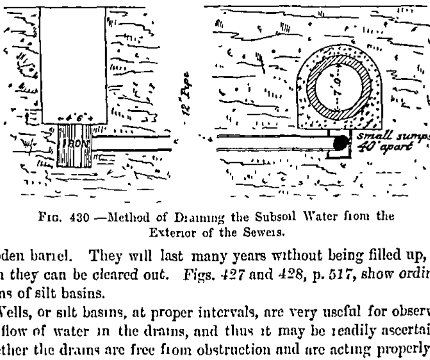


Fig. 430.—Method of Draining the Subsoil Water from the Exterior of the Sewers.

wooden barrel. They will last many years without being filled up, and then they can be cleared out. Figs. 427 and 428, p. 517, show ordinary forms of silt basins.

Wells, or silt basins, at proper intervals, are very useful for observing the flow of water in the drains, and thus it may be readily ascertained whether the drains are free from obstruction and are acting properly.

as shown in Fig. 3, Plate XLIV., opposite, which gives the details of the work required in connection with outfalls for either a small or large system of drainage. An iron plate, with the date and number on it, should be let into the masonry, and entered on the drainage plan. The site of all the drains should be correctly shown on the plan.

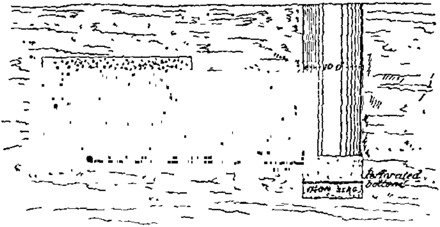


Fig. 429.—Method of Draining the Subsoil Water from the Exterior of the Sewers

Silt Basin.—*Silt basins should be formed on mains at junctions* where there is likely to be a great flow of water, or at the foot of an incline in the drain, where there is a change of the fall to one less steep. They may be formed of brickwork, or with a large pipe on end, or with a

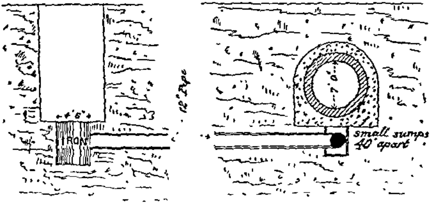


Fig 430.—Method of Draining the Subsoil Water from the Exterior of the Sewers.

wooden barrel. They will last many years without being filled up, and then they can be cleared out. Figs. 427 and 428, p. 517, show ordinary forms of silt basins.

Wells, or silt basins, at proper intervals, are very useful for observing the flow of water in the drains, and thus it may be readily ascertained whether the drains are free from obstruction and are acting properly.

Sumps: Use of.—Where it is necessary to drain below natural outlets, such as on sites only a little above high water level, the water may be carried into sumps or wells, from which it can be passed off by pumping, or by valves, to let it run out at low water.

To prevent the subsoil water forcing its way into sewers, drains should be laid to carry it off. Figs. 429 and 430, p. 518, show the method adopted in the Main Drainage Works of London to drain the subsoil water from the exterior of the sewers.

Air Drains.—An increased rapidity of discharge from a long main drain, or one of slight inclination, is obtained if air is admitted directly to it, and an air drain connecting the upper ends of the minor drains has also been advocated. Such contrivances would apparently be advantageously employed in the case of the denser clays, but this would not obtain with porous soils.

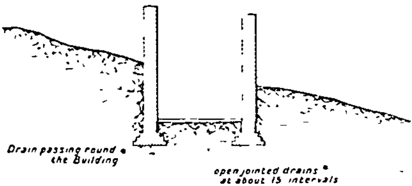


FIG. 431.—Drainage Underneath a Building.

Clay Soil.—The worst ground for a site is a clay soil, or a clay subsoil, coming near the surface; but the disadvantages will be reduced to a minimum, if not entirely removed, by efficient subsoil drainage.

It is desirable that the subsoil drains should be below the level of the footings of the walls of a building, and that they should lead away from it without passing under it.

Drainage under Foundations (Fig. 431).—It may be necessary in some cases to lay drains under foundations, in addition to the ordinary subsoil drainage, to guard against water from below rising into them. Such drains should be laid with a considerable fall into the adjacent subsoil drains, or the water from them should be carried away from the site by an independent drain; they should not form any part of the main system of drainage of the site, so that in case of any stoppage of a drain underneath the foundations, no water could find its way under the building from the surrounding drainage.

Surrounding Site.—It will be found a great advantage to put in subsoil drains surrounding the immediate site, if possible, to a depth below the footings of a building, before making excavations for the foundations, as the water will thus be prevented from running into the trenches.

Special for Footings.—If the excavations are carried below the depth of the subsoil drains, it will be desirable to drain them separately by carrying off the water to a lower level. In special cases this may not be possible, and it may be necessary to leave the site undrained, building in below ground with hydraulic mortar or cement, and afterwards draining in the ordinary way around the building. In such a position the subsoil water may be kept out of the trenches by sheeting and puddling, if it cannot be kept under by pumping.

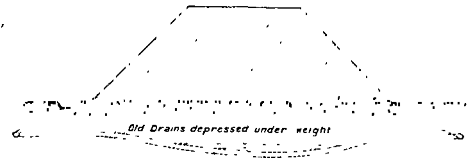


FIG 432.—Section through Railway Embankment, showing Depression of Drains.

Where the subsoil drains are not below the level of the foundations, the whole area under the building, and above the level to which the drainage is laid, should be covered with a layer of concrete.

For Peaty Soil.—In ground of a peaty nature it is essential that, if it be drained at all, the drains should be laid before the work is commenced, as such a site is seriously affected by the drainage, and the substratum becomes easily compressible.

Railway Embankment.—When any great weight of earth, such as a railway embankment or a parapet, is to be placed on a site which is already drained, the drainage should be made independent on each side of the site and lead outwards from it and clear of it, as shown in Fig. 432, to ensure the proper drainage being maintained, and to avoid the risk of the drains under the embankment being stopped up by the compression of the soil under the superincumbent weight.

Drains through Foot of.—It is often advisable to lay open-jointed drains at intervals through the foot of an embankment near the natural surface of the ground to carry off the water which may sink into the made earth, and might cause it to slip or settle; and with retentive soil, it may be necessary to insert drains on the top and down the faces of the embankment to prevent its slipping. When it is required to carry any part of

the drainage underneath the embankment, a small culvert should be formed, or a pipe drain jointed in cement carefully laid should be provided, in order to avoid the risk of any accumulation of water underneath.

Trenches, Depth of.—The trench for a subsoil drain is usually from three to six feet deep, and is cut as narrow as possible for the depth.

The amount of excavation for the required depth will depend a good deal upon the skill of the excavator, and upon the nature of the soil. The bottom need only be sufficiently wide to take the pipes, provided the excavation can be made without the workmen having to stand in the trench. The tops will be from one to two feet wide, and the sides sloping, as shown in Figs. 433, 434.

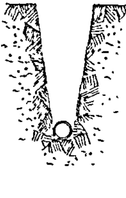


FIG. 433.

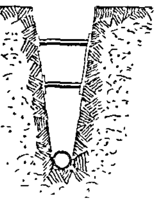
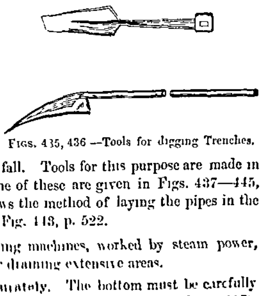


FIG 434

Trenches for Subsoil Drainage

Ordinary Tools.—Machines.—It will generally be found more economical to let the workman make the trench of the width he can conveniently manage, rather than insist, in every case, upon a very narrow trench. Many special forms of spades and scoops are made and recommended to be used in digging trenches, but workmen will rarely be found to use with advantage tools to which they are unaccustomed. But narrow spades and scoops, as Figs. 435, 436, should, if possible, be used for excavating and finishing off the bottom of the trenches to the required fall. Tools for this purpose are made in a great variety of shapes; some of these are given in Figs. 437—445, p. 522. Fig. 446, p. 523, shows the method of laying the pipes in the trench by means of the tool in Fig. 443, p. 522.



FIGS. 435, 436.—Tools for digging Trenches.

Machines.—Special excavating machines, worked by steam power, are used to cut the trenches for draining extensive areas.

Bottom to be Graded Accurately. The bottom must be carefully trimmed to the true inclination (*vide* Plate XLIV., p. 518, also p. 107),

FIG. 437.

FIG. 438

FIG 439.

FIG 440.

FIG. 441

FIG. 442.

FIG. 443.

FIG. 444

FIG 445

FIGS. 437—445.—Tools for Excavating Trenches for Subsoil Drains.

every part being tested with boning rods. Where the soil is very loose or formed in running sand, the bed for the pipes should be formed with a layer of stiff soil or clay. This will not, as might be supposed, stop water rising into the pipes, as after a short time it becomes quite porous.

Pipes.—Material and Size.—The pipes in general use for subsoil drains are circular, though several other shapes used to be manufactured. They are made of clay similar to that used for ordinary bricks, and are burnt in the same way as bricks. Those two inches in diameter and upwards are usually made in lengths of 12 to 15 inches and are generally used for minor or lateral drains, up to 16 chains in length. For larger drains, 2½ or 3-inch pipes should be used

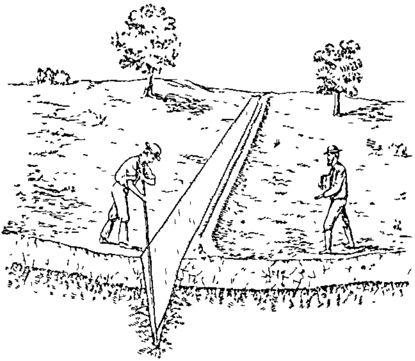


FIG. 446.—Application of Special Tool in laying Pipes.

at the lower parts. Collars are sometimes made to encircle the joints of pipes, but they are seldom used on account of the increased expense. They are valuable in preserving the continuation of the drain, but in the case where pipes of smaller bore than two inches would be used, the increased difficulty of preserving the continuity is got over by not using any pipes under two inches diameter of bore. Their use would be advisable in sandy soil, to check the tendency of the pipes to become choked with silt. It has been found by experiment that by far the larger part of the water enters the pipes through the joints, and only a small percentage

these drains are more expensive than those with properly laid pipes, and are, moreover, very liable to become obstructed.

Hand Packing.—A dry packing of stones in embankments, at the back of revetment walls, or in the foundation of roads, is frequently used with advantage to facilitate drainage.

Brushwood.—Drains are sometimes formed with brushwood, pieces of wood, or sods, as a means of getting rid of soakage water. In exceptional cases, when tile pipes are not available, these substitutes may be advantageously applied. All such drains must be regarded as makeshifts, very inferior to tile drains.

Boggy Land.—Wet, boggy land is very troublesome to drain properly. It is not often used as a site for buildings, but it may lie near to dwelling-houses, and, therefore, require draining. The ordinary tile draining has, in many instances, proved useless in such cases, because the drains have been laid before the ground was in a fit state to receive them. The drying out of such land is a gradual process, which must be carefully developed. One or more deep, open ditches should be dug along the lines on which the main drains will eventually run. They should not be less than five feet deep, and the sides must be at such a slope that they will not be liable to fall in.

Trenches about a foot in depth will then be cut across the surface of the ground at intervals of ten to fifteen feet, with a good fall to the open ditches. As the soil dries and consolidates, these trenches are gradually deepened, the bottom being frequently cleared out to allow an uninterrupted flow of water through them. When they have been made to a depth of about two feet, if the ground is drying well, it may be possible to dispense with each alternate drain, deepening the others by degrees to a depth of four feet, and keeping them open till they have been proved to work satisfactorily, and the ground has become fairly firm; then, but not till then, pipes may be laid. It will be as well to use collars for the pipes, as the bottom of the trench will probably be rather soft, and 2-inch pipes should be used.

Failure of Drains.—Every precaution should be taken to prevent obstructions occurring in drains. If properly constructed, they should last for fifty years without requiring to be re-laid. In low land, however, when the soil is composed of fine materials, it frequently happens that the pipes have to be taken up and re-laid after about ten years, and in peaty soils this may be necessary after three or four years.

The chief causes of obstructions are silt, vermin, and roots.

Silt.—Silt will be deposited wherever there is slack water, owing to a defect in laying, or to an irregularity in the shape of a pipe, or to a decrease of the fall in the drain.

The entrance of silt into the pipe may be to a great extent prevented by having collars on the pipes, or by covering them with a few inches of gravel or other porous soil, and placing over this a layer of compact clay, so that the water may enter at the bottom of the tiles instead of at the top, as already mentioned. The deposit of silt in the pipes may be guarded against by the provision of silt basins.

Vermin.—Vermin, such as mice, obstruct the pipes by making nests in them, and dying in them. To obviate this difficulty, and keep them out of the pipes, the outlet openings should be covered with a grating or wire guard, or be protected by packing broken glass bottles around them. The outlets shown in Fig. 3, Plate XLIV., p. 518, have been used for this purpose.

Roots of Trees.—Roots of many trees, especially willows, will enter pipes, and extend within till they sometimes completely stop up the pipes. However, this difficulty does not occur very frequently. Where it has occurred it has been necessary to take up the pipes and re-lay them with socket joints in cement through the ground where the roots are likely to extend, say within about fifty yards of the trees.

Plan of Drains.—The positions of the several drains, outfalls, sumps, and examining holes, should be shown upon the plan of the drainage area. The depths, sizes of pipes, and inclinations at the several places should also be marked upon it. It must be expected that the drains will have to be opened at some time or other, so a proper record of them will save much expense in searching for them, and enable an intelligent supervision of every part of the drainage system to be readily maintained, and consequently prompt remedial measures to be taken should any defect be discovered.

CHAPTER XIV.

SANITARY NOTES.

Made Ground.*—"The surface soil of London, and also of many other *large cities and towns, is a mixture of mould, gravel, or clay, with debris of* ancient buildings and rubbish. Much of this has been upturned over and over again, so that it comprises an accumulation of brick-bats, fragments of crockery, and what not, commingled with relics of the soil and subsoil. In a few localities in London it has accumulated steadily, or at irregular intervals, at the rate of from six inches to one foot a century. Much of the 'made ground' is thus of ancient date, and in these undisturbed areas it has preserved trophies of the Roman occupation, of the Great Fire, and other interesting episodes. Made ground may be from a foot or two to about twenty-five feet in thickness, the greater thicknesses being here and there due to the in-filling of old pits. At the Bank of England there were twenty-two feet of made ground resting on four feet of gravel. Such artificial 'soil' of varying character and thickness no doubt extends over the whole of old London. Mr. Whitaker has remarked that Belgravia is probably in great part built on ground of this character, otherwise it would be lower and damper. In itself made ground is not always an unsatisfactory foundation for a house. Much of it, as we have stated, is of an ancient date; moreover, good material may artificially be brought to level an irregular tract. The serious matter is that in these enlightened days it is possible for houses to be erected on pits in which all kinds of rubbish, with decaying vegetable and animal matter, have recently and intentionally been shot. Sir Douglas *Galton has spoken strongly on this subject, and he asks, 'What, then,* can be more dangerous, what more wicked, than the every-day proceedings in the metropolis, and elsewhere, of those persons who purchase a building site, who extract from it the healthy clean gravel and sand which it contains, allow the holes to be filled with rubbish, and then proceed to build upon it?' It is well known that injurious emanations

* *Memoirs of the Geological Survey.* [illegible], by Mr. Horace B. Woodward, F.R.S.

come from an impure soil or subsoil, and may rise into a house; so that on such an unwholesome foundation it is absolutely necessary that the basement be securely cemented. The bye-laws of the Local Government Board will, it is hoped, prevent any further building of houses on polluted sites."

Natural Soil.—The natural soil is of varied composition, being primarily derived from the subsoil, which may itself be regarded as the weathered portion of the underlying hard or soft strata. With the decomposed mineral ingredients of the soil is mingled more or less decayed animal and vegetable matter, while the whole soil layer has been largely re-constituted as mould by the action of earth-worms and micro-organisms. Wind-drifted material has also to some extent modified the constituents of soil. As a rule the natural soil is too thin to have any particular effect on the sanitary conditions of a site, although in places it may be as much as three feet or more in thickness. It is naturally thicker on the lower slopes of hills and in valleys, owing to its downwash by rain from the higher grounds. It is usually thicker also on the sandy and loamy areas than on the stiff clays.

The Influence of Subsoil Water on Health.—Mr. S. Monckton Copeman, M.A., etc., writes in the *Journal of the Sanitary Institute*, April, 1896, as follows:—"A survey of all the recorded work on the influence of subsoil water on health appears then to show that rapid and abnormal oscillations of the level of the subsoil water are particularly dangerous, such variations being of considerably greater importance than the actual distance of the ground water from the surface. Other things being equal, it is doubtless true that the further the ground water from the surface, the healthier will be the site, although in all probability a higher average level without obstruction to the outflow will not necessarily be more conducive to the appearance of disease, so long as the height is not such as to bring about more or less permanent dampness of dwellings.

"As I have already stated, it would appear that with the exceptions perhaps of cholera and typhoid fever, the condition of the upper layer of the soil, as regards the amount of moisture in its interstices, is of more importance than the actual level of the ground water beneath."

Steam, Admission of, to Sewer.—No steam exhaust, blow-off or condensed water from any boiler, or hot water from any manufacturing process (such water being of a higher temperature than 110 degrees Fahrenheit), should be allowed to be connected direct with the sewer or with any drain connected to the sewer—such pipes should first discharge into a tank or condenser, from which a suitable outlet to the sewer should be provided.

Drains to be Tested.—All drains should be tested before a house is occupied, and afterwards annually, especially if any of the drains run under the building.

An inspector can only ascertain the general design of the drainage arrangements by examining the building; the nature of the workmanship can only be judged by the application of suitable tests.

It is not at all an easy matter to make a reliable inspection of the drainage of a building, and especially so of an old drainage system. In the latter case the examination can never be considered *complete* until every drain, branch, soil, ventilating or waste pipe, has been traced and tested from end to end.

According to the *Sanitary Record*, April 15th, 1893:—"The reliable and successful drain-tester must possess a certain amount of inventive ability and be of ready resource; above all, he must have great patience, and must find out everything for himself as indicated by the tests, and not take anything for granted; and information given to him by those who profess to know should be gratefully received, but at the same time he should satisfy himself of its accuracy and value."

The following description of house inspection more particularly refers to an old house, but the same system, with modification, is of general application.—

House Inspection.—"Sanitary engineers consider that an unusual smell is generally the first evidence of something wrong, and that, traced to its source, the evil is half cured. They inspect first the drainage arrangements. If the basement generally smells offensively, they search for a leaking drain-pipe, *i.e.*, a pipe badly jointed or broken by settlement, and these will often show themselves by a dampness of the paving around. If, upon inquiry, it turns out that rats are often seen, they come to the conclusion that the house drain is in direct communication with the sewer, or some old brick barrel-drain, and therefore examine the traps and lead bends which join the drain-pipes to see if they are gnawed or faulty. If the smell arises from any particular sink or trap, it is plain to them that there is no ventilation of the drain, and more especially no disconnection between the house and the sewer, or no flap-trap at the house-drain delivery into the sewer.

"If a country house be under examination, a smell at the sink will, in nearly every case, be traced to an unventilated cesspool; and, in opening up the drain under the sink, in such a state of things, they will take care that a candle is not brought near, so as to cause an explosion. If the trap is full of foul, black water, impregnated with sewer-air, they partly account for the smell by the neglect of flushing. If the sink, kitchen, and scullery wastes are in good order, and the

smell is still observable, they search the other cellar rooms, and frequently find an old floor-trap without water, broken and open to the drain. If the smell be ammoniacal in character, they trace the stable-drains, and see if they lead into the same pit, and if so, argue a weak pipe on the route, especially if, as in some London mansions, the stable-drains run from the mews at the back, through the house, to the front street sewer.

"Should a bad, persistent smell be complained of mostly in the bedroom floor, they seek for an untrapped or defective closet, a burst soil-pipe, a bad junction between the lead and the cast-iron portion of the soil-pipe behind the casings, etc., or an improper connection with the drain below. They will examine how the soil-pipe is jointed there, and, if the joint be inside the house, will carefully attend to it. They will also remove the closet framing, and ascertain if any filth has overflowed and saturated the flooring, or if the safe underneath the apparatus be full of any liquid. If the smell be only occasional, they conclude that it has arisen when the closet-handle has been lifted in ordinary use, or to empty slops, and satisfy themselves that the soil-pipe is unventilated. They, moreover, examine the bath and lavatory waste-pipes, to ascertain if they are untrapped, and, if trapped by a sigmoidal bend, see whether the trapping water is not always withdrawn owing to the syphon action in a full-running pipe. They will trace all these water-pipes down to the sewer, ascertain if they wrongly enter the soil-pipe, the closet trap, or a rainwater pipe in connection with the sewer.

"If the smell be perceived for the most part in the attics, and, as they consider, scarcely attributable to any of the foregoing evils, they will see whether or not the rainwater pipes which terminate in the gutters are solely acting as drain ventilators, and blowing into the dormer windows. They will also examine the cisterns of rainwater, if there be any in the other portions of the attics, as very often they are full of putridity.

"A slight escape of impure air from the drains may be difficult to detect, and the smell may be attributed to want of ventilation, or a complication of matters may arise from a slight escape of gas.

"Neither are all dangerous smells of a foul nature, as there is a close, sweet smell which is even worse. Should the drains and doubtful places have been previously treated by the inmates to strongly-smelling disinfectants, or the vermin killed by poison, the inspectors of nuisances will find it difficult to separate the smells. In such a case, however, they will examine the state of the ground under the basement flooring, and feel certain that there are no disused cesspools or any sewage saturation of any sort. They will also ascertain if there be any stoppage in the

drain-pipes by taking up a yard-trap in the line of the drain, and noting the re-appearance of the lime-water which they had thrown down the sink. And invariably, after effecting a cure for any evil which has been discovered, they will have the traps cleaned out and the drains well flushed.

"A thoroughly-drained house has always a disconnection chamber placed between the house-drain and the sewer, or other outfall. This chamber is formed of a raking syphon and about two feet of open channel-pipe, built around by brickwork, and covered by an iron manhole. Fresh air is taken into this chamber by an open grating in the manhole, or by an underground pipe, and the air thus constantly taken into the chamber courses along inside the drain, and is as continuously discharged at the ventilated continuations of the soil-pipes, which are left untrapped at the foot, or at special ventilating pipes at each end of the drain. This air current in the drain prevents all stagnation and smell.

"When a house is undergoing examination, it is wise to test for lighting-gas leakages, and there is only one scientific method of doing so, which is as follows Every burner is plugged up save one, and to that is attached a tube in connection with an air force-pump and gauge—the meter having been previously disconnected. Air is then pumped into the whole system of pipes, and the stop-cock turned, and if, after working the pump for some time, and stopping it, the gauge shows no signs of sinking, the pipes may be taken as in safe condition; but if the mercury in the gauge falls, owing to the escape of air from the gas-tubes, there is a leak in them, which is discoverable by pouring a little ether into the pipe close by the gauge, and re-commencing pumping. Very minute holes can be detected by lathering the pipes with soap and water, and making use of the pump to create soap bubbles.

"Besides the drainage, they will, especially if they detect a bad and dank smell, see if it arises from the want of a damp-proof course, or of a dry area; see if there be a wet soil under the basement floor, a faulty pipe inside the wall, an unsound leaden gutter on the top of the wall, or an overflowing box-gutter in the roof, a leaky slatage, a porous wall, a wall too thin, and so on.

"They will also keep an eye upon the condition of the ventilating arrangement, and whether the evils complained of are not mainly due to defects there. The immediate surroundings of the house will also be noted, and any nuisances estimated.

"Sanitary inspectors, whilst examining into the condition of the drains, always examine the water cisterns at the same time, and discover whether the cistern which yields the drinking water supplies as well the flushing water of the closets. They will also ascertain if the overflow

pipe of the cistern, or of a separate drinking-water cistern, passes directly into the drain. If the overflow pipe be syphon-trapped, and the water rarely changed in the trap, or only when the ball-cock is out of order, they will point out the fallacy of such trapping, and, speaking of traps generally, they will look suspiciously on every one of them, endeavour to render them supererogatory by a thorough ventilation and disconnection of the drains."*

After making a careful examination of the premises, the best method of testing the drains can be decided on; the most efficient and trustworthy test where it can be applied is the "hydraulic" or "water test."

Drain Testing.

Hydraulic or Water Test.—This test involves subjecting the drains and joints to a pressure of a head of water of at least six feet. In order to effect this it is necessary to plug the lower end of the drain by means of a drain plug or an air bag, as described below. The most convenient place for applying the plug is at a disconnecting pit or just above the intercepting trap. In order to obtain the necessary head of water a bend and a couple of lengths of pipe on end may be temporarily attached to the upper end of the drain and set in cement, so as to retain the necessary water. A more convenient arrangement is to apply one of Addison's drain stoppers (Fig. 455, p. 538) at the upper end also, when the necessary head can be readily obtained by attaching a piece of indiarubber tubing to the brass tube through its centre; the water can be filled in through a funnel.

If no such convenience as a disconnecting pit or intercepting trap exists, the drain-pipe would have to be opened and plugged as already described.

The level of the water should be carefully marked, and any subsidence after a period of, say, two hours, would indicate a fault somewhere, *and it would then become necessary to uncover it and examine it* carefully.

It is generally necessary to test the different sections of a large system of drainage separately. The plugs would then be inserted from the inspection pits or manholes; if there are gullies at various levels they can be similarly plugged if circular in section.

Soil-pipes should similarly be subjected where practicable to either the "water test" or to the "pneumatic test," as a greater pressure can thus be obtained which will reveal defects that would pass unnoticed by either the peppermint or smoke tests; but there is a difficulty in the universal application of the "water test" which does not exist in the "pneumatic test," presently to be described.

* Parkes' *Hygiene*

The Pneumatic Test.—This test consists in the substitution of air under pressure for the water used in the hydraulic test. One of the great advantages it possesses over the latter is that it can be readily applied to vertical soil pipes and house fittings for which the hydraulic test is more or less inapplicable; the pressure exerted is also susceptible of modification according to circumstances. Drain stoppers are used to close the outlets, traps and ventilating shafts where necessary to confine the air which is pumped into the drains, etc., either by the Eclipse smoke generator (Fig. 458, p. 539) or by other suitable apparatus. A few strokes of the pump handle are all that are required, and if after this the copper float is found to remain stationary, the inference may be made that the drain is sound, if however it falls a leakage is indicated; this should then be localised by the additional use of the smoke or peppermint test.

It should be remembered that a pressure of 10 lbs. corresponds to a height of 20 inches of mercury.

The following extract from his book has been furnished by Mr. G. Jensen*:—

"The great advantage which the air-test possesses over the water-test, is that the pressure applied by the former is uniform and of equal severity on each part of the drainage system, whereas it varies greatly in intensity in the case of the water-test, the lower portion of the drain having to withstand a much greater pressure than the upper end. In addition to this, the test may be applied at all times and under all conditions, without reference to weather or lack of water. A rainy day, for instance, is fatal to a water test, as the rain will find its way into the drains and make it impossible to ascertain whether they are sound or leaking. With an air-test, on the other hand, the admission of water to the drain, be it by rain or through a waste pipe, will have no effect than to increase the pressure within the drain. Any excessive pressure will, moreover, be immediately released by the safety valve, should it be undesirable to test above any given pressure." The apparatus referred to above is Jensen's pneumatic drain-testing machine (Fig. 457, p. 539), which seems especially well adapted for the purpose.

Peppermint and Smoke Tests.—In the case of old drainage, in order to ascertain whether there is anything defective in the traps, apparatus, or joints of pipes, resulting in the emission of sewer-gas at improper places, the drains may be tested by either the peppermint or smoke tests, which will be found very convenient for the purpose, but the pipes must be uncovered to make it effective. The peppermint test is at best only a very rough and ready test and should only be resorted to when other means are not available.

* *Modern Drainage Inspection and Sanitary Surveys.*

Instructions for Peppermint Test.—Carefully close all ventilating pipes from soil-pipes or drains; ventilating shafts from drains; inlets for fresh air to drains, or soil-pipes, etc., by means of a damp cloth or some clay.

Place about a table-spoonful of the crude oil of peppermint in the pan of the topmost w.c., and gradually pour in about a gallon of hot water. If the peppermint makes itself felt inside the house, or in the drain outside, it indicates a defect in the soil-pipes or drains. Care must be taken to tightly close the door of the w.c., stopping all the cracks, and the person putting the peppermint down must not emerge until the test has been finished, as he, of course, would taint the air in his vicinity, consequently two persons must be employed in applying the test. (Petroleum, terebene, oil of rosemary, ether, or other strong-smelling essential oil may also be used, but peppermint is considered the best for the purpose.)

This should be repeated in the lower w.c.'s, so as to test all the sinks, aths, yard gullies, and any other outlet for water connected with the ins. An outside gully may be similarly utilized for applying the test, better still one of the ventilating pipes on the roof of the house, carefully plugged after pouring down the hot water

The Pneumatic Test.—This test consists in the substitution of air under pressure for the water used in the hydraulic test. One of the great advantages it possesses over the latter is that it can be readily applied to vertical soil pipes and house fittings for which the hydraulic test is more or less inapplicable; the pressure exerted is also susceptible of modification according to circumstances. Drain stoppers are used to close the outlets, traps and ventilating shafts where necessary to confine the air which is pumped into the drains, etc., either by the Eclipse smoke generator (Fig. 458, p. 539) or by other suitable apparatus. A few strokes of the pump handle are all that are required, and if after this the copper float is found to remain stationary, the inference may be made that the drain is sound, if however it falls a leakage is indicated; this should then be localised by the additional use of the smoke or peppermint test.

It should be remembered that a pressure of 10 lbs. corresponds to a height of 20 inches of mercury.

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This should be repeated in the lower w.c.'s, so as to test all the sinks, baths, yard gullies, and any other outlet for water connected with the drains. An outside gully may be similarly utilized for applying the test, but better still one of the ventilating pipes on the roof of the house, which should be carefully plugged after pouring down the hot water charged with the peppermint.

Smoke Test.—The smoke test should be applied by using one of the smoke-testing machines used for this purpose. "The Eclipse smoke generator" (Fig. 458, p. 539) is a very good one; the pipe can be introduced into the drain through the water seal of a trap.

The ventilators from soil and other pipes should not be closed until a constant discharge of smoke from their open ends is observed. When these openings are stopped the smoke in the pipes is subjected to pressure which assists in detecting flaws in the pipes and apparatus.

The smoke should either be forced into the drains through a gully outside of the house, or advantage taken of a ventilating opening so as to test the pipes and fittings for w.c.'s, baths, sinks, or other apparatus directly connected with the drains, and where the drains run under any portion of a building, the smoke should be forced up the drain towards the house. If any smoke is visible in the house, or any smell of the fumigating material can be detected, it indicates defects in the drains or pipes sufficient to admit sewer-gas into the house.

It is very necessary, when applying the smoke test, to make certain that the smoke actually passes into all branch pipes, and that it comes into close contact with the joints between the drain and every fitting. A convenient way of proving this is to withdraw the water from traps by means of a syringe; the smoke should then be freely emitted.

The outside drains should also be tested in section between the various

traps and gullies; if they consist of old brick or stone drains, they probably leak, and are contaminating the earth.

Drain Plugs or Stoppers.

Special drain plugs or stoppers are most useful in connection with drain testing. There are a great many varieties in the market; the "Addison" patent drain stopper (Fig. 455), manufactured by Nicholls & Clarke, appears to be a serviceable article.

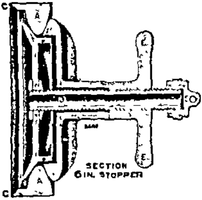

Fig. 455.—The Addison Patent Drain Stopper.

Instead of having a bolt and nut by which to draw up the flanges, a brass tube and nut are used, to which an indiarubber supply tube can be very readily connected for use, either with water, smoke, or other tests.

The rubber ring A is made with a large surface to press against the inside of the pipe, and is provided with a lip C, so that the pressure of water on it tends to make the joints more secure. These stoppers expand about five-eighths of an inch, thus allowing for variations in the sizes of pipes by different makers. The rubber cannot pinch between the two discs, as it is held in position by the guide B. The stopper is fitted with an inside tube D, sealed by a screw cap F, which, when unscrewed, allows the water to escape after being used for testing. The expanding is easily effected by screwing the nut E, which is provided with long wings for the purpose.

They are supplied in the following sizes:—4, 5, 6, 8, 9 and 10 inches.

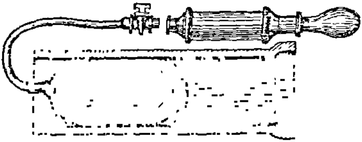

Fig. 456.—Jones's Patent Pipe Stopper.

Jones's Patent Pipe Stopper.—Another patent drain-pipe stopper (Fig. 456), for applying the water test to drains, or arresting the flow when they are under repair, etc., consists of a bag of indiarubber, or some such material, to which is attached a flexible tube with a tap at the end connected to a small hand-pump. The bag is placed in the

drain before inflation, and by working the pump it is quickly filled with air under sufficient pressure to dam up the drain or prevent any escape of gas. Turning off the tap causes the bag to collapse, when it can be removed. These bags are made in different sizes to suit various diameters, and have secured the approbation of most leading sanitary scientists.

The Jensen Pneumatic Drain-testing Machine.—"It consists of a force-pump (A) (Fig. 457), such as is used for inflation of drain bags, by means of which air is pumped into the drains, and an attachment consisting of a pressure gauge (B) and a safety valve (C). The gauge indicates the pressure applied to the drains, whilst the safety valve enables the Inspector to regulate the maximum pressure to be applied. Should he, for instance, desire to apply a test of 3 lbs. to the square inch, the safety valve is set at that pressure. On pumping, any pressure in excess of the 3 lbs. will be immediately liberated. The pump is screwed on to the cock D, the cock E being provided for attachment to a tube passing through the plug or bag with which the drain has been stopped. When the desired pressure has been obtained, the cock D is closed, and if the drains are leaking, the reduction of pressure in the drains will be indicated on the pressure gauge" (*Modern Drainage Inspection and Sanitary Surveys*).

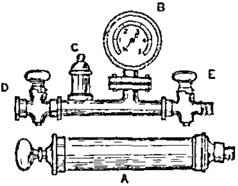

FIG 457.—Jensen's Pneumatic Drain-testing Machine

SMOKE GENERATORS

The Eclipse Smoke Generator, referred to on p. 537, is shown in Fig. 458. Messrs. Burns & Baillie, the manufacturers, claim that

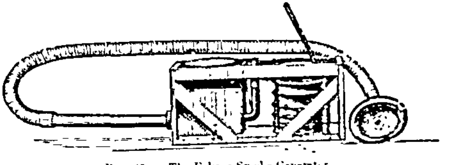

FIG. 458.—The Eclipse Smoke Generator

this is the only smoke generator which applies a positive test to drains. It consists of a double-action bellows covered with specially prepared

tests, due to mismanagement or the careless handling of the necessary chemicals.

Kemp's Patent Drain Tester.—This is a very useful *invention*, and is represented in Fig. 463. It is very easy of application: it is only necessary to remove the cover of the box and then secure the cover, lowering the "tester" into the w.c. pan or gully; a pail of water, preferably hot, should be immediately thrown into the trap to wash the "tester" into the drain, where the contents will be at once discharged, producing a strong odour and a large volume of smoke in the drain. Defects can be readily detected by the pungent gas and smoke thus made finding its way through defective points, etc. The string with the spring and cap attached can be withdrawn from the trap, so as to prove that the contents has been satisfactorily discharged. Their cost is 1*s.* each, post free.

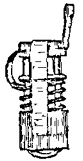

Fig 463.—Kemp's Patent Drain Tester.

Pain's Smoke Cases or Rockets are intended to be placed in the drain. They are provided with a couple of thin strips of wood which when turned at right angles to the case extend on either side sufficiently to keep it off the invert of the pipe; these rockets burn for a considerable time, and emit a dense volume of smoke with a pungent smell. They are supplied by James Pain & Sons.

Burnett's Patent Smoke Drain Tester.—The use of this test is exemplified in Fig. 464. The test is shown inserted in the trap, which should be done after flushing it with water; the match is ignited, and the smoke case is passed through the water by means of the handle into the drain side of the trap. To find the outgo of the trap, a slight twisting movement of the handle is all that is necessary while inserting it. The tester should be left in the trap for about ten minutes before withdrawing it. By this means the drain is charged with a dense and pungent smoke, which will readily escape through any defect in the drain, thus showing plainly by sight and smell where it exists. The manufacturer is Mr. H. E. Burnett.

Fig. 464.—Burnett's Patent Smoke Drain Tester.

Disinfectants and Disinfecting.

Disinfectants.—The term "disinfectant," which is now in general use, is employed in several senses. By some it is applied to every agent that can remove impurity from the air; by others, to any substance which, besides acting as an air purifier, can also *modify chemical action* or restrain putrefaction in any substance, the effluvia from which may contaminate air; while by others again it is used to designate the substances which can prevent infectious disease from spreading by destroying their specific poisons.

Experiments have been conducted to determine the action of various disinfectants, in a greater or less state of concentration, upon definite microbes, and it has been found possible to define the degree of concentration necessary to constitute some of the chemical substances so employed as germicides. Many powerful deodorizers are not germicides, unless highly concentrated, although they may for a time render organisms inert by preventing their growth without actually destroying them.

The following list it is thought may be useful, and is, therefore, appended:—

Disinfectants, Powerful or Germicides.—Capable of destroying the most resistant microbes, under certain stated conditions of strength, temperature, and time.—Fire, boiling water, steam, hot dry air, per*chloride* of mercury, carbolic acid, *izal*, cressol, iodine, trichloride, osmic acid, permanganate of potash, iodine water, chlorine water, bromine water, formalin.

Disinfectants, Weak.—Capable of destroying microbes which are not in the state of spore.—The powerful disinfectants more diluted, chloride of lime, hydrochloric acid, sulphurous acid, salicylic acid, chromic acid, creosote, caustic lime, soda, and potash.

Antiseptics.—Capable of impeding or arresting the growth of microbes, but without necessarily destroying them.—Sulphate of zinc, chloride of lime, sulphate of copper, sulphate of iron, perchloride of iron, boracic acid, borax carbolic oil,* thymol,* oil of turpentine,* eucalyptus oil.

Deodorizer, but not an Antiseptic.—Permanganate of potash (Dibdin).

Aërial Deodorants.—For fumigation. Chlorine gas, sulphurous acid, nitrous fumes, ozone, euchlorine, formalin.

Powders for Disinfecting Purposes.—Manufactured and sold by the various makers whose *names* are given in the brackets. Izal powder (Newton, Chambers & Co.), sanitary powder (Jeyes), sanitas (Sanitas Co), eucalyptol (Mackey, Mackey & Co.), chloride lime (Greenbank

* Chiefly used as deodorants for concealing odours.

Alkaline Co.), surgical and tooth powder (Jeyes), carbolic acid (Mackey & Co.), pinewood and eucalyptus (Mackey & Co.), boro phenol (Calvert), kanphorkalk (A. Hornby), oxynite.

Liquids for Disinfecting Purposes.—Manufactured and sold by the various makers whose names are given in the brackets. Izal (Newton, Chambers & Co.), phenol (Bobemf), perfect purifier and Jeyes' liquid (Jeyes), terebene (Cleaver), eucalyptol, camphorine, sulphenic acid, oxychlorogene, cresylic acid, carbolic acid (Mackey, Mackey & Co.), emulsion (Sanitas Co.), kresyline (Mackey), pixine (J. Wheeler).

Use of Disinfectants.—In any district where an epidemic prevails or is threatening, disinfection of all water-closets, etc., should be carried on systematically, either with solutions of chloralum, cupralum, carbolic acid, Burnett's fluid, or perchloride of mercury. Izal soap is very serviceable for scouring the floors of hospitals, sick rooms, etc.

Any manure heaps, or other accumulations of filth that might exist, which it is inexpedient to disturb or impossible to remove, should be covered with powdered vegetable charcoal to the depth of two or three inches, or with a layer of fresh dry earth, or with freshly-burnt lime, if charcoal cannot be obtained.

Cesspits and midden heaps may be disinfected with solutions of copperas (3 lbs. to the gallon of water), or with cupralum or chloralum (1 lb. to the gallon of water).

Cooper's salts might be used for the streets, lanes, and open courts. It need hardly be said, however, that in a town or district well looked after by the sanitary authorities no such filth accumulation as above mentioned would be allowed to take place at any time. [See *Handbook of Hygiene* (Wilson), page 385.]

Izal.—Izal, which is a comparatively new disinfectant, extracted from an unknown oil obtained from certain coke ovens, is a creamy looking emulsion, having an earthy smell, coupled with a faint odour suggestive of phenol. It is readily mixed with water, forming a milky emulsion. The following notice of izal appears in the *Theory and Practice of Hygiene*, by J. Lane Notter, M.A., M.D., and R. H. Firth, F.R.C.S. :—

Its disinfecting properties have been extensively investigated by us and found satisfactory. A 20 per cent. emulsion destroyed the highly resisting spores of *B. subtilis* and *B. mesentericus* in thirty-five minutes. A 10 per cent. emulsion killed virulent spores of anthrax bacilli in twenty minutes. Non-spore bearing specimens of the above bacilli were destroyed after five minutes' exposure to 0.5 per cent., or 1 in 200 emulsion. A 0.3 per cent. emulsion destroyed the streptococcus of pus; and exposure for half an hour to a 1 per cent. emulsion was sufficient to destroy the enteric fever bacillus and the spirilla of cholera.

Our observations dispose us to regard izal as a disinfectant of considerable practical value, and that for concrete cases of disinfection of morbid materials from

the various infectious disorders, an exposure for fifteen minutes in the strength of 1 per cent will be sufficient. Moreover, izal, being free from poisonous properties, when introduced by injection into the tissues, or when administered by the stomach, possesses qualities which practically no other efficient disinfectant affords. The inhibitory or antiseptic value of izal is equally defined, as neither spores, micrococci, nor non-sporing bacilli and spirilla can germinate in medicated media, if the amount of disinfectant added is 0 1 per cent.

Formalin.—Formalin is the short term given by the Schering factory to a saturated 40 per cent. solution of formic aldehyde, the product of imperfect oxidation of alcohol. Formalin is supplied in various forms in a liquid state, and also in a dry form for *gasification; the gas is harmless and* antiseptic, it has great penetrating power. Dry formalin in any quantity is absolutely harmless to the human organism, but is convertible into active formalin gas by a very simple and easily managed contrivance in the shape of a lamp (the "Alformant," Fig. 465), patented by the Formalin Hygienic Co. in this country. This lamp had to be so constructed that when the stable body "paraform" was in the action of subliming, a sufficient quantity of water and carbonic acid should be led over the product of sublimation to convert it into active formic aldehyde, and this could be done by no other medium than the water of combustion supplied by a spirit flame. The whole of the paraform, by proper application, can thereby be converted into formalin gas, and the supply of gas is thus rendered simple and concise. Dr. A. B. Griffiths states: "Paraform, or formalin in tablets, is a white solid, and is the polymer of formalin; it is a stable chemical compound not altered by heat, and only moderately antiseptic." This formalin gas obtained by means of the "Alformant" is far more effective as a germicide and a deodoriser than anything in the market. It may be stated that 1 gramme of paraform is equal to 2½ grammes of liquid formalin, which is the saturated aqueous solution of 40 per cent. of gas. Formalin is supplied by the Formalin Hygienic Co., Limited.

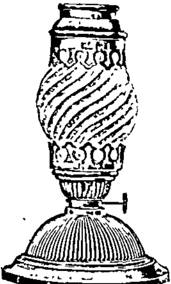
FIG. 465.—The "Alformant" Disinfecting Lamp

Reevozone.—Charges of Reevozone for purifying the air in sewers are supplied by Reeves Chemical Sanitation, Limited. A very strong oxygenating vapour is evolved by the reaction of the chemicals, which deodorises and disinfects the sewer-air, and at the same time a strong

disinfecting and deodorising solution is discharged into the sewer. The value of this system, from a public health point of view, lies in the fact that in the event of an epidemic occurring the whole of the sewer-air throughout the entire extent of any system of sewerage can be immediately purified ; and it is claimed, as the result of a practical trial, that if this were done the health officers would be in a position to almost instantly arrest the course of any zymotic outbreak occurring in their districts. The whole sewerage of a fair-sized town could be dealt with in a few hours. For further information about the Reeves system *vide* page 393, *ante*.

Condy's Fluid.—Condy's fluid, red and green, consists of a solution of potassium permanganate. It is essentially an oxidizing agent. It is odourless, and very useful for pouring down drains and w.c.'s. It arrests putrefaction for a short time, and prevents smell.

Chloride of Lime.—Chloride of lime is most powerful as a deodorant, and also as a steriliser, especially at a high temperature.

Calvert's Carbolated Creosote.—Calvert's carbolated creosote is stated to be very effective for use in drains should any disease be known to be in the locality. The net cost per gallon for not less than forty gallons is 1*s.* 6*d.*, the cask being 6*d.* extra. About a quarter of a pint would be added to an ordinary bucketful of water. It is readily applied to the drains by supporting the cask over a small water tank connected by an overflow pipe and syphon with the drain.

Water can be turned on to the tank at any speed desired, and the proportional supply of carbolated creosote can similarly be regulated by a tap in the cask for drawing it off.

This plan has been adopted by Mr. C. Jones, C.E., Borough Engineer at Ealing.

Method of Application.—The method usually adopted for the application of disinfectants for purifying houses, rooms, etc., is to close all openings or apertures in a house or room, and employ the fumes of sulphurous acid, chlorine, nitrous acid, or other gases, with the object of destroying the germs of disease. But as these gases are truly aërial deodorants, the object in view is not always effected.

It is, therefore, thought best to give an extract from the report of a process recommended by Drs. Dupré and Klein.

Extract from a Report by Drs. Dupré, F.R.S., and Klein, F.R.S., on the Best Method of Disinfecting the Room where Enteric Fever has occurred.

"Recent investigations have shown that gaseous substances, such as sulphurous acid gas and chlorine gas, which have been often used for

the purpose of disinfecting rooms and similar localities, cannot be relied on, and that the only disinfectant that can be depended upon to kill micro-organisms, particularly those capable of producing the infectious diseases, is a free application of a solution of perchloride of mercury. It is well to have this solution slightly acid, coloured also in such a way that it shall not readily be confused with drinks or medicines, and proper caution should be given to prevent accidents in its use.

"The solution is made by dissolving half an ounce of corrosive sublimate and one fluid ounce of hydrochloric acid in three gallons of common water, with five grains of commercial aniline blue, or *ordinary violet ink, to give the fluid a conspicuously distinguishing* character. Proper caution should be given to avoid accidents, as the solution is a deadly poison.

"The solution is easily made, keeps well, is very inexpensive, and should not be further diluted, and is easily applied. The use of non-metallic vessels (wooden or earthenware house tubs or buckets) should be enjoined on those who use it.

"The method of applying the disinfectant will, no doubt, vary under different conditions, but the following may be taken as an outline of the procedure that should be usually adopted:—

"The walls should be thoroughly stripped of all paper or other covering and scraped. All skirting should be removed. The floor *boards should be taken up, and all rubbish and dust found in the space* under the joists should be removed, care being taken that the scrapings, rubbish and dust are not thrown away, but are burnt, as they may contain infectious germs.

"After a thorough clearance has been made, as described above, the whole of the ceilings, walls, joists, architraves and window linings, and any other fixed woodwork in the rooms, together with the spaces below the floors, should be carefully washed with the solution of perchloride, prepared as above directed. The solution should be applied with a whitewasher's brush.

"A syringe should be used to squirt the solution into any nooks or interstices which the whitewasher's brush will not properly reach. Whenever used, the solution should be liberally applied, and should be allowed to remain overnight.

"Any dilapidated flooring or woodwork should be *burnt, and only* the thoroughly sound portions should be re-fixed, and these, before being fixed, should be thoroughly washed with the solution, allowed to remain over night, and afterwards washed with warm water, in order to remove the mercury.

"Ceilings and walls should be limewashed, and all fixed woodwork should also be washed with warm water, in order to remove the

mercury." (*See Report on the Sanitary Condition of the Richmond Barracks, Dublin,* by Mr. Rogers Field, C.E.)

In executing the above recommendations, the workmen should be provided with special clothing, *e.g.*, white duck to fit over their ordinary apparel, respirators, goggles and gloves, and, further, they should be made to wash their faces before leaving work, at meal-time, etc.

DISINFECTION OF CLOTHES, BEDDING, ETC., BY HEAT.

The Local Government Board had prepared by Dr. H. F. Parsons, M.D., an exhaustive series of experiments upon the disinfection of clothing, etc., by heat, and the results of these experiments form the subject of a Report* which was published in 1886, and from which the following extracts have been made :—

Dr. Parsons first determined, in conjunction with Dr. Klein, the most suitable infective matter as the true test of disinfection, and studied the virus of swine plague, of tuberculosis, and of anthrax, all of which admit of being put to the test upon animals, both before and after experimental heating.

The observers came to the conclusion that of these infections anthrax material was the most resistant to every form of heat, and they proceeded on the assumption that arrangements which would afford a heat adequate to destroy anthrax, not only in its bacillar but in its spore form, might be trusted to destroy the potency of infectious matter generally.

Having determined by a prolonged series of experiments the degree of heat to be attained and the combinations with moisture in which the heat was best operative, Dr. Parsons examined the physical conditions necessary for its production in the required combinations; and then continued his research into practical questions concerning the mechanism by which the needful conditions for heat disinfection could be obtained. It was seen to be necessary so to arrange an apparatus that heat should penetrate bulky and non-conducting articles, and so that the heat could be used to dainty fabrics without injury to their appearance or to their texture.

Dr. Parsons came to the conclusion that all infected articles which could be treated by boiling water, so as to penetrate the substance efficiently by this means, without injury to the articles themselves, could not be so well disinfected in any other way as by simple boiling for a few minutes; that infected articles which from their nature did not lend themselves to such boiling had best be treated with high-pressure steam, with such arrangement as would ensure penetration of the steam at its high temperature, and that such treatment might

* Extracts from the Annual Report of the Medical Officer of the Local Government Board for 1884. "Disinfection by Heat." Eyre & Spottiswoode, 1886.

be relied on to destroy any infective quality in them with the thoroughness and rapidity that were desired; and that in the comparatively few cases where the articles to be disinfected would be injured by steam, a dry heat of 240° Fahr. would, if sufficiently prolonged, bring about the desired destruction of infection, but that this could not, in the case of most articles, be had by means of dry heat without an inconvenient length of exposure.

The general effect of Dr. Parsons' Report was that there is no sort of disinfector or disinfectant equal to heat, and that of all the methods of applying heat the use of high-pressure steam is by far the most generally available.

The results of Dr. Parsons' experiments were conclusive as to the destructive power of steam at 212° Fahr. upon all contagia submitted to its action.

In one instance only was there room for suspicion that the disinfection had not been complete. This was in the case of highly resisting anthrax spores exposed to steam for five minutes only.

As disinfection by heat is frequently used for the destruction of vermin in clothing, experiments were made to test the efficiency of steam for this purpose, and it was found that lice were easily killed by exposure to heat, and that the eggs of lice exposed for ten minutes to steam at 212° Fahr., or which had been boiled for five minutes in water, would not develop.

In order to secure the thorough and certain disinfection by heat of porous articles likely to retain infection, such as clothing and bedding, it is necessary that the heat shall be made to permeate the articles in every part to such a degree and for such a length of time as to destroy all infectious matter. It is true that the outer casing of such articles as pillows and mattresses is more liable to become soiled with infectious matters than the inner parts, yet the soaking of such articles with liquid discharges and the movement of air which takes place within them would lead to the introduction of infected particles into the interior of such articles.

Heat may be propagated in several ways:—

(1) It may be radiated from a heated solid body.

(2) It may be conducted through the substance of bodies, especially solid bodies. The conducting power of different substances varies greatly, being greatest in dense substances such as metals, and least in those which are light and porous in texture.

(3) Heat is also conveyed through fluids, liquid or gaseous, by currents set up by the alteration in density due to expansion by heat.

There is a marked difference between the distribution of temperature in a chamber heated primarily by a radiant heat and one heated by the admission of hot air or steam.

Radiant heat is most intense close to its source, diminishing rapidly as we recede from it: also it does not turn corners, and thus objects lying behind others are screened from it except so far as it may be reflected upon them from other surfaces.

On the other hand, if heated air or steam be admitted into a chamber the temperature tends to equalise itself in the different parts, and the walls and heavy contents of the chamber are heated to an equal degree.

Bedding, blankets, etc., are articles offering the highest resistance to the passage of heat, and they are therefore exceedingly difficult to disinfect, and experiments were made to ascertain the relative conducting power of such articles, and also of feathers, flocks, horsehair, rags, etc., the general result of which was that to procure penetration by heat of bulky articles of badly conducting material, high pressure steam is by far the best agent.

As examples of the thorough efficiency of this medium, the following cases may be quoted.

A bale of cotton rags weighing 180 lbs. was exposed for a period of 1 hour to steam at 15 lbs. pressure (equal to a temperature of 251° Fahr.) *showing a temperature in the centre of the bale of 242° Fahr.* With steam at 30 lbs. pressure in the jacket of the disinfector and 15 lbs. in the interior, relaxed every half hour, a temperature of 255° Fahr. was obtained in 2 hours in the centre of a bale of woollen rags weighing nearly 5 cwt.

By a similar exposure of 4 hours a temperature of 258° Fahr. was obtained in the centre of a press-packed bale of cotton rags weighing 5 cwt. On the other hand, in an experiment with the bale of rags above referred to when exposed for 5 hours to a temperature of 272° Fahr. in air without pressure, a temperature of only 192° Fahr. in the centre was obtained.

The penetration of heat in the form of steam is considerably aided by pressure and is further assisted by relaxing the pressure from time to time and re-applying it.

The latter effect is probably produced by displacing the cold air remaining in the interstices of the material, and this is particularly

infected articles from submitting them to disinfection. If articles cannot be exposed to a temperature sufficient for disinfection without some risk of injury, there is the danger that in order to avoid this risk the articles will not be heated to a temperature sufficiently high or sufficiently prolonged to ensure their being disinfected.

The principal modes in which injury may occur to articles subjected to disinfection by heat differ somewhat in the case of steam from that of dry heat, and are as follows:—

(1) Scorching or partial decomposition of organic substances by heat. In its incipient stages this manifests itself by changes of colour, changes of texture and weakening of strength.

(2) Overdrying, rendering materials brittle.

(3) Fixing of stains so that they will not wash out.

(4) Melting of fusible substances such as wax and varnish.

(5) Alterations in colour, gloss, etc., of dyed and finished goods.

(6) Shrinkage and felting together of woollen materials.

(7) Wetting.

Overdrying of course can only occur when dry heat is employed, wetting only when steam or boiling water is used. Shrinkage takes place more with steam than with dry heat. Scorching is more liable to occur with dry heat than with steam.

(1) Scorching occurs with different materials at different temperatures. It occurs sooner in woollen materials such as flannels and blankets than with cotton or linen, whilst horsehair will bear a higher temperature still.

Most materials will bear a temperature of 250° Fahr. without much injury, but when this temperature is increased signs of damage soon begin to appear.

Flannel and blankets exposed to steam at 260° Fahr. for half-an-hour acquire a distinctly yellow tinge and their tensile strength is somewhat diminished; while flannel exposed to dry heat of 220° Fahr. for four hours or a steam heat of 228° Fahr. for half-an-hour acquires a slight yellow tinge, but its tensile strength is not appreciably impaired.

Table 96, p. 552, shows the results of experiments made by Dr. Parsons. In the experiments with dry heat the breaking strain was not tested until after the lapse of a day or more, so that the materials had had time to regain their hygroscopic moisture.

As it appeared possible that the heat or moisture might affect the threads of the warp or woof differently, experiments in the case of flannel were made with strips torn lengthwise as well with others torn across the breadth of the piece.

It will be seen that the colour and tenacity of white flannel were affected by even a moderate exposure to heat; blankets also were

deteriorated in a minor degree. Cotton, black cloth, and silk, white and coloured, were little affected by temperatures under 300°, though the tensile strength, especially of cotton, was somewhat impaired. The behaviour of leather is curious: it will bear a moderate application of dry heat, but is utterly disorganised by a short exposure to steam, being shrivelled and converted into a gelatinous texture, which becomes very hard when dry. See Table 97, p. 553.

TABLE 96.

Material.	Exposed to	Time.	Shrinkage per cent	Tensile Strength before and after.	Colour.
White flannel......					
" length	Steam 264°	½ hr.	6·0	100 : 88	Distinct yellow tinge
" breadth	" "	"	5·7	100 : 88	
" length	" 228°	"	5·4	100 : 97	Yellowish tinge.
" breadth	" "	"	4·1	100 : 96	
" length	" 212°	"	5·8	100 : 92	Slight yellowish tinge.
" breadth	" "	"	6·0	100 : 100	
" length	Dry heat 220°	4 hrs.	1·6	100 : 107	Yellowish tinge
" breadth	" "	"	0·8	100 : 98	
" length	" 280°	2 hrs.	2·0	100 : 100	Yellow tinge dark in places.
" breadth	" "	"	0·4	100 : 95	
" length	Simple washing		6·6	100 : 132	Very slight change.
" breadth	Simple washing		7·4	100 : 102	
" length	Boiling water	½ hr.	8·4	100 : 85	Dirty yellowish tinge.
" breadth	Boiling water	"	6·9	100 : 95	
Tape, Cotton	Steam 260°	4 hrs.	?	100 : 82	Little alteration.
"	" 251°	½ hr.	1·4	100 : 80	
"	" 212°	½ hr.	2·0	100 : 77	
"	Dry heat 230°	4 hrs.	0·35	100 : 73	No discoloration, lost glaze.
"	" 280°	2 hrs.	0·7	100 : 73	Slightly darkened.
"	Boiling water	½ hr.	2·7	100 : 73	Lost glaze.
Black Cloth*......	Steam 251°	½ hr.	0·9	100 : 100	No alteration.
"	" 212°	½ hr.	0·0	100 : 90	Slightly discoloured.
"	Dry heat 230°	4 hrs.	0·0	100 : 100	Slightly rusty as if from long wear.
"	" 280°	2 hrs.	0·8	100 : 100	Do. more marked.
"	Boiling water	½ hr.	0·0	100 : 100	Discoloured, dye having run.
White Silk Ribbon	Steam 251°	½ hr.	2·1	100 : 100	No alteration
"	" 212°	½ hr.	2·0	100 : 100	" "
"	Dry heat 230°	4 hrs.	0·7	100 : 87	No change in colour, less glossy.
"	" 280°	2 hrs.	0·35	100 : 60	Brownish tinge scorched.
"	Boiling water	½ hr.	1·0	100 : 100	Lost glaze.

* This sample of cloth had apparently been already shrunk.

TABLE 97.

Articles	Exposed to	Time	Results
Kid glove.........	Steam 250°	½ hr	Shrivelled up and converted into a gelatinous substance, very hard when dry
"	" 212°	5 minutes	Shrivelled up and converted into a gelatinous substance, very hard when dry
"	Dry heat 212°	1 hr.	Unaltered
	228°	5 minutes	Greatly distorted by softening of felt and disorganisation and shrivelling of leather lining
		1 hr.	Unaltered.
			Yellowish and brittle.
			Yellow tinge.
			[illegible]llow tinge, puckered some[illegible]hat hard and threadbare

occur where the heat is in the radiant form. To avoid risk of scorching the heat should not be allowed much to exceed 250° Fahr., and even this temperature is too high for woollen articles.

4. By a heat of 212° Fahr. and upwards, whether dry or moist, many kinds of stains are fixed in fabrics so that they will not wash out. This is a serious obstacle in the way of the employment of heat for the disinfection previous to the washing of linen, etc., soiled by the discharges of the sick.

5. Steam disinfection is inapplicable in the case of leather, or of articles which will not bear wetting. It causes a certain amount of shrinkage in textile materials, about as much as an ordinary washing. The wetting effect of the steam may be diminished by surrounding the chamber with a jacket containing steam at a high pressure so as to superheat the steam in the chamber.

6. For articles that will stand it, washing in boiling water (with due precautions against re-infection) may be relied on as an efficient means of disinfection. It is necessary, however, that before boiling, the grosser dirt should be removed by a preliminary soaking in cold water. This should be done before the linen leaves the infected place.

7. The objects for which disinfection by dry heat or steam is especially applicable are such as will not bear boiling in water, *e.g.*, bedding, blankets, carpets, and cloth clothes generally.

8. The most important requisites of a good apparatus for disinfection by heat are (*a*) that the temperature in the interior shall be uniformly distributed; (*b*) that it shall be capable of being maintained constant for the time during which the operation extends; and (*c*) that there shall be some trustworthy indication to the actual temperature of the interior at any given moment. Unless these conditions be fulfilled, there is risk, on the one hand, that articles exposed to heat may be scorched, or on the other hand, that through anxiety to avoid such an accident the opposite error may be incurred, and that the articles may not be sufficiently heated to ensure their disinfection.

9. In dry-heat chambers the requirement (*a*) is often very far from being fulfilled, the temperature in different parts of the chamber varying sometimes by as much as 100° Fahr. This is especially the case in apparatus heated by the direct application of heat to the floor or sides of the chamber. The distribution of temperature is more uniform in proportion as the source of heat is removed from the chamber, so that the latter is heated by currents of hot air rather than by radiation.

10. In chambers heated by gas, when once the required temperature has been attained but little attention is necessary to maintain it uniform, and in the best made apparatus this is automatically per-

formed by a thermo-regulator. On the other hand, in apparatus heated by coal or coke the temperature continually tends to vary, and can only be maintained uniform by constant attention on the part of the stoker.

11. In very few hot-air chambers did the thermometer with which the apparatus was provided afford a trustworthy indication of the temperature of the interior; in some instances there was an error of as much as 100° Fahr. This is due to the thermometer, for reasons of safety and accessibility, being placed in the coolest part of the chamber, and to the bulb being enclosed for protection in a metal tube which screens it from the full access of heat. The difficulty may be overcome by using, instead of a thermometer, a pyrometer actuated by a metal rod extending across the interior of the chamber.

12. In steam apparatus the three requirements above mentioned are all satisfactorily met, and for this reason, as well as on account of the greater rapidity and certainty of action of steam, steam-chambers are, in my opinion, greatly preferable to those in which dry heat is employed.

13. It is important that the arrangement of the apparatus, the method of working, and the mode of conveyance to and fro, should be such as to obviate risk of articles which have been submitted to disinfection coming into contact with others which are affected.

The Nottingham Steam Disinfecting Apparatus

The apparatus consists of a steel boiler with safety valve, water gauge, pressure gauge, and force pump enclosing the closet, 5 feet × 5 feet × 6 feet 6 inches back to front, open at each end, with a gauge for showing the pressure inside. (See Fig. 466, p. 562)

The ends are closed by two hollow steel doors, connected to the boiler in such a manner by pipes that water is drained away and steam is always circulating through them; consequently the inside closet is surrounded by the inner skin or plates of the boiler, which keeps the sides at an equal temperature with that of the steam. Thus there is absolutely no possibility of any condensation taking place. There is also a chamber built in the flues for heating the air, connected to the disinfecting closet by a pipe and valve. The apparatus is supplied with an exhauster, connected to the closet by the pipe and valve. Upon opening the valve and starting the exhauster, a strong current of hot air passes through the closet, and coming in contact with the articles inside, prepares them for the admission of steam.

After articles have been disinfected and the steam exhausted, the hot air is again turned on to carry off any steam remaining in the closet. The articles when taken from the closet are perfectly dry and [illegible]

occur where the heat is in the radiant form. To avoid risk of scorching the heat should not be allowed much to exceed 250° Fahr., and even this temperature is too high for woollen articles.

4. By a heat of 212° Fahr. and upwards, whether dry or moist, many kinds of stains are fixed in fabrics so that they will not wash out. This is a serious obstacle in the way of the employment of heat for the disinfection previous to the washing of linen, etc., soiled by the discharges of the sick.

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7. The objects for which disinfection by dry heat or steam is especially applicable are such as will not bear boiling in water, *e.g.*, bedding, blankets, carpets, and cloth clothes generally.

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THE NOTTINGHAM STEAM DISINFECTING APPARATUS.

The apparatus consists of a steel boiler with safety valve, water gauge, pressure gauge, and force pump enclosing the closet, 5 feet × 5 feet × 6 feet 6 inches back to front, open at each end, with a gauge for showing the pressure inside. (See Fig. 466, p. 562.)

The ends are closed by two hollow steel doors, connected to the boiler in such a manner by pipes that water is drained away and steam is always circulating through them; consequently the inside closet is surrounded by the inner skin or plates of the boiler, which keeps the sides at an equal temperature with that of the steam. Thus there is absolutely no possibility of any condensation taking place. There is also a chamber built in the flues for heating the air, connected to the disinfecting closet by a pipe and valve. The apparatus is supplied with an exhauster, connected to the closet by the pipe and valve. Upon opening the valve and starting the exhauster, a strong current of hot air passes through the closet, and coming in contact with the articles inside, prepares them for the admission of steam.

After articles have been disinfected and the steam exhausted, the hot air is again turned on to carry off any steam remaining in the closet. The articles when taken from the closet are perfectly dry and do not

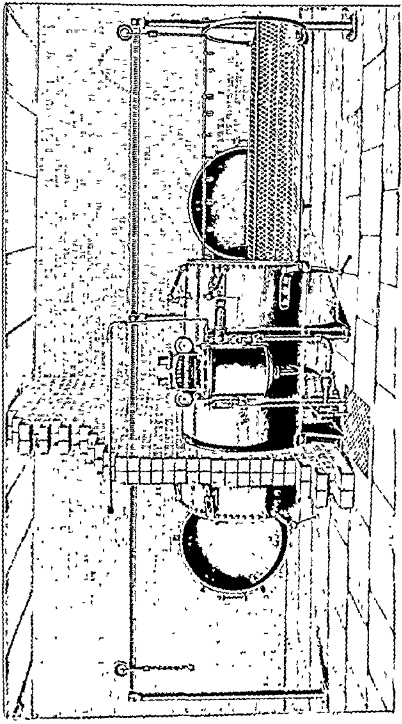


Fig. 466.—The Nottingham Steam Disinfecting Apparatus

show signs of the treatment; no matter how delicate the fabric, it is hardly possible to damage it by this process.

The method of working the apparatus is as follows:—A fire is lighted and the closet filled with the articles to be disinfected. The doors are closed and screwed up, making a perfectly steam-tight joint. In the meantime the steam has risen to 20 lbs. pressure per square inch on the boiler, blowing off at the dead weight safety-valve. This latter is of such a size that the steam cannot rise above 20 lb. pressure, thus preventing any damage which could occur through inattention. The exhauster is now set to work by opening the valve and steam supply, causing a current of hot air to pass through the valve into the closet, thoroughly drying the articles.

After this operation has continued for some little time the valves are closed. The steam is then admitted to the closet by another valve, and in about two minutes the pressure in the closet and boiler are the same as shown on the gauges. The pressure is then increased until it blows off at the safety valve. The articles are left in the closet from twenty to thirty minutes according to their character. Then the steam valve is closed, and the valve to exhauster opened; this operation allows the steam in the closet to escape, the pressure soon falling to zero. The valves are again opened, the hot air passed through the closet, displacing any steam in it which would condense on the articles when the door is opened, also thoroughly drying the articles which have been disinfected. In a few minutes the door may be opened, the valves closed, and the disinfected articles taken out on the opposite side of the apparatus to which they are put in.

A temperature of 250° Fahr. is considered sufficient to destroy all germs of infectious disease. Steam at 20 lb. pressure has a temperature of over 259° Fahr., so that not only is the temperature amply sufficient, but steam at 20 lbs. pressure almost immediately penetrates the articles even when the *most non-conductible material.*

This apparatus is manufactured by Messrs. Goddard, Massey & Warner, of Nottingham, and by Messrs. Manlove, Alliott & Co., Nottingham.

A somewhat similar apparatus to the above, but on a much smaller scale, is manufactured by the above-named firms for sterilising surgical dressings, instruments, etc., for use in operating theatres and hospitals.

SANITARY MAXIMS.*

1. It is the duty of every householder to ascertain for himself whether his own house be free or not from well-known dangers to health.

* By T. Pridgin Teale, M.A., as published by the National Health Society, Berners Street, London.

2. This duty, imperative at all times, is of surpassing urgency in a house where a confinement is expected, or a surgical operation to be performed.

3. As a rule, the soundness of the sanitary arrangements of a house is taken for granted, and never questioned until "drain-begotten" illness has broken out. In other words, we employ illness and death as our drain detectives.

4. Whenever gas from sewers, or the emanations from a leaking drain, a cesspool, or a fouled well, make their way into a house, the inmates are in imminent danger of an outbreak of typhoid fever, diphtheria, or other febrile ailment, classed together under the term "zymotic," not to speak of minor illness and depressed vitality, the connection of which with sewer-gas is now fully established. Sewer-gas enters a house most rapidly at night when the outer doors and windows are shut, and is then perhaps most potent in contaminating the meat, the milk, and the drinking water, and in poisoning the inmates.

5. The more complete and air-tight the public sewers of a town, the greater the danger to every house connected with such sewers, if the internal drain-pipes of the house be unsound and not *disconnected*. In houses so badly connected, sewer-air is "laid on" as certainly for the detriment of health as coal gas for illumination; and you can turn off coal gas at the meter.

6. Every hotel throughout the kingdom and in our watering places, every house let as lodgings, ought to have its sanitary arrangements periodically inspected and duly licensed.

7. A house in which children and servants are often ailing with sore throat, headache, or diarrhœa, is probably wrong in its drainage.

8. Scamped drain work is one of the most dangerous of the sanitary flaws of new buildings; it is also one of the most common and one of the most difficult to detect, and is rarely found out except by means of the illness it produces.

9. If you are about to buy or to rent a house, be it new or be it old, *take care, before you complete your bargain*, to ascertain the soundness of its sanitary arrangements with no less care and anxiety than you would exercise in testing the soundness of a horse before you purchase it.

10. If you are building a house, or if you can achieve it in an old one, let no drain be under any part of your house, *disconnect* all waste pipes and overflow pipes from the drains, and place the soil pipe of the w.c. *outside* the house and ventilate it.

11. If there is a smell of drains in your house, or a damp place in a wall near which a waste pipe or a soil-pipe runs, or a damp place in the cellar or kitchen floor near a drain or a tank, let no time be lost in laying bare the pipes or drains until the cause be detected.

12. If a rat appears through the floor of your kitchen or cellar, and a strong current of air blows from the rathole when chimneys are acting and the windows and doors of the house are shut, feel sure that something is wrong with a drain.

13. If you are tenants and your landlord refuses to remedy the evil, do it at your own cost rather than allow your family to be ill.

14. Many a man who would be aghast at the idea of putting small quantities of arsenic into every sack of flour, and so by degrees killing himself and family, does not hesitate to allow sewer-gas to poison the inmates of his house, even in the face of the strongest remonstrances of his medical adviser.

15. A landlord may reasonably look for interest on money which he spends for the benefit of his tenant; but he is committing little short of manslaughter if, by refusing to rectify sanitary defects in his property, *he saves his own pocket at the expense of the health and lives of his tenants.*

16. If you be a landlord, do not intimidate your tenants or threaten to give them notice to quit if they complain of defective drainage or sewer-gas in the house.

CHAPTER XV.

SEWAGE DISPOSAL.—THE PROBLEM.

Efficient Removal Necessary.—It has already been pointed out that it is most essential to health to provide for the efficient removal of all decomposing refuse, as well as the foul water, from houses and factories as soon as possible, before putrefaction sets in; the question of its final disposal then becomes a matter of the greatest importance.

At one time, when communities were small, the final disposal of their sewage was accompanied with but little difficulty; the sea or the nearest river were the natural receivers into which it was poured without hesitation, and without any apparent harm or injury to other communities situated lower down the stream. In the former case, no evil results followed, and in the latter also the action of the stream is of such a nature as to purify the sewage to a great extent by processes which are now daily becoming better understood; the quantity, however, must not be too great.

Self-Purification of Rivers.—It had long been recognised that Nature carried on unaided in rivers and streams the process of purification of pollutions, but the extent of such self-purification had not been the object of special and prolonged observations on an extensive scale until the Royal Commission on Sewage Disposal took the matter up.

The following information is extracted from the reports made by Professor Boyce, and Drs. MacConkey, Grunbaum, and Hill, to the Commission on Investigations of the River Severn in the neighbourhood of Shrewsbury.

From these it appears that the stretch of the river over which the investigations were made measured 26 miles, starting from the County Asylum 2 miles above Shrewsbury Waterworks, and ending at Iron Bridge 24 miles below.

The width of the river varied on this length considerably at different points, the average being 200 feet, the depth in the broadest parts in dry weather being inconsiderable.

The velocity and discharge of the river varied within very wide limits, as the following figures will show:—

On July 12, 1900, the velocity was estimated at 30 feet per minute, the volume at the same time being 112 million gallons per twenty-four hours; on January 6, 1901, the velocity was 180 feet per minute with a volume of 1,055 million gallons.

The streams entering the Severn are comparatively few in the length under observation, and with one exception are fairly clean.

The town of Shrewsbury draws the water which it uses for domestic purposes from the river, and the intake is at a point where the river has already commenced to flow through the town.

Within a comparatively short distance the whole of the sewage of a town of 28,396 inhabitants was discharged into the river without treatment.

In 1896 the normal dry weather flow of sewage of Shrewsbury was estimated at 844,000 gallons per twenty-four hours, so that the total sewage entering the river from the town was about 1 per cent. of the volume of the stream, and in exceptionally dry weather the proportion of sewage might be greater.

The conclusions of the experts were as follows :—

(1) That the *B. coli* is a most reliable test of pollution.

(2) That the *B. coli* is normally absent in 1 c.c. quantities of water taken from the Vyrnwy watershed of the River Severn.

(3) That when the *B. coli* is present in a small stream, contamination from houses can be traced.

(4) That small land drains are comparatively free from *B. coli*.

(5) That the small streams running into the Severn often contain considerable quantities of the *B. coli* due to contamination from proximity to houses.

(6) That the sewage of Shrewsbury causes a very great increase in the number of *B. coli* in the river, and that 16 miles lower down the effect of pollution can still be detected by the number of *B. coli* present.

(7) That there is no evidence of the multiplication of the *B. coli* in the river water.

(8) That the *B. coli* is present in considerable numbers in the mud of the Severn in the polluted area, and that this mud may be the means of keeping up and extending pollution, but that there is no evidence of the multiplication of the *B. coli* in the mud.

(9) That there is comparison between [illegible] of bacteria and *B. coli*, but the relative proportion of the latter to the former is small.

(10) That [illegible] er-ficial and d[illegible] in stagnant b[illegible] be taken.

(11) That sedimentation and side adhesion to the banks of the solids in suspension take place, and that at places in the bed of the river anærobic fermentation occurs, whilst along the banks, especially in the wind and water line, ærobic bacteria actively help to destroy the organic matter.

(12) That certain places in the river are very deep, and that these act as catch-pits, that the stream in these places is sluggish, and that sedimentation is favoured.

(13) That in the destruction of organic matter, whether solid or in solution, whilst the bacteria take the greatest share, help is also rendered by the protozoa and higher forms of animal life, by the sewage fungi, the chlorophyl containing protophytes and the river plants.

(14) That the *Sphaerotilus natans* is a test of sewage pollution, and that it is a purifier of sewage.

(15) That there is no evidence to show that pathogenic bacteria multiply in either the water or mud of the river.

(16) That seasonal variations in the number of bacteria occur, but taking the *B. coli* as the test for pollution that the number of this organism is dependent upon the numbers present in the sewage entering the river, and that when the river is swollen and muddy the number is small owing to increased dilution, and that when the river is low the number is large owing to the lesser degree of dilution which the sewage undergoes when it enters the river.

(17) That the effect of dilution of the river upon the sewage of Shrewsbury is most marked. That the average maximum number of *B. coli* in the river is only 600 per c.c., which is much less than in an average Dibdin effluent, whilst a short distance below pollution the number decreases very considerably.

(18) That there is a relationship between chemical and biological analyses.

(19) That the River Severn is a good example of a river which it would be difficult to class either as a potable or non-potable stream. It is true that the inhabitants of Shrewsbury consider it as non-potable, for they do not drink the water; but they use it for washing purposes, nd consequently there is always a liability for, say, milk to become ontaminated by being kept in a can which was washed with the river rater. This liability is increased by the fact that the river is ractically used as a tidal river, receiving as it does the whole of the ntreated sewage of the town. Again, the river in close proximity to he town is used largely for watering cattle. Cattle may therefore ontract disease from the water, and such disease may be communicated uman beings.

The river is also used for fishing and has a recreative and ornamental value.

For these reasons we consider that it is as worthy of protection from pollution as any so-called potable river.

That whilst it would be onerous to expect absolute sterility in any effluent running into such a stream unless some simple method of sterilisation were discovered, yet a certain degree of bacterial purity, as shown by the *B. coli* test, might be insisted upon in addition to the chemical tests, for it would indicate the extent to which the intestinal bacteria were reduced by the method of sewage treatment employed.

(20) That what has been described in this report upon the effects of allowing crude sewage to enter the River Severn is also applicable to biological effluents. Crude sewage is an example of the worst form of pollution; the effluents from biological methods of treatment are examples of a lesser degree of contamination, because the solids in suspension in the latter are far less in amount and are in a fine state of division, and the number of the *B. coli* is smaller.

Shrewsbury with 29,000 inhabitants, and turning crude sewage into the Severn, causes an average pollution of 600 *B. coli communis* per c.c. (at the point of maximum pollution) and this is felt 16 miles lower down. But if a large town like Leeds were similarly situated, and the sewage were purified by contact beds so as to contain 10,000 *B. coli communis* per c.c., the pollution would still be about 1,000 *B. coli communis* per c.c., and if 600 *B. coli communis* are felt for 16 miles, 1,000 would be felt still further down. Consequently in spite of the artificial purification, such a river would be in a worse condition than the Severn at Shrewsbury, which is admittedly bad. It follows that the purification thus attained would be insufficient, and that some further treatment would still be necessary.

The chemical results obtained demonstrated that the River Severn showed a marked recovery from its Shrewsbury pollution within 20 miles from the town.

A further series of observations were made upon the River Thames, commencing at Hampton above the tidal portion of the river and the water companies' intakes, and continuing down to Barrow Deeps, 48 miles below the Crossness sewer outfall, by Dr. A. C. Houston, who formed the following conclusions:—

I. The water of the River Thames at Sunbury and Hampton, above the intakes of some of the London Water Companies, is so far unsatisfactory *from the bacteriological point of view* as almost to justify its description as extremely dilute sewage; as, for instance, sewage diluted 1,000 to 10,000 times.

II. The Barking (Northern outfall) and Crossness (Southern outfall)

"chemically produced" effluents resemble in their biological composition raw sewage; they contain about 100,000 coli-like microbes and about 100 to 1,000 spores of *B. enteritidis sporogenes* respectively per c.c. During 1902 the combined volume of effluent from the Barking and Crossness works amounted to a daily average of 232 million gallons.

III. The bacteriological condition of the River Thames at Barking, Crossness, and Purfleet is *very unsatisfactory.*

Crossness is about two miles below Barking, and Purfleet about five miles below Crossness. Speaking in general terms, the water at these places contained about 100 to 1,000 coli-like microbes, and usually 1 to 10 spores (but more often 10 than 1 spore) of *B. enteritidis sporogenes*, per c.c.

IV. At Grays, about five miles lower down the river than Purfleet, the water showed *some slight evidence of improvement, particularly* as regards the *B. coli* test.

V. At Mucking, *about ten miles below Grays, the Thames water* shows definite signs of improvement.

With regard to coli-like microbes, 11·5 per cent. of the samples contained 100, 57·7 per cent. contained 10, and 30·8 per cent. contained 1 per c.c.

As regards *B. enteritidis sporogenes*, about one-third of the samples contained 10 spores and about two-thirds 1 spore per c.c.

Judged on this basis, therefore, the water at this point was, as regards the *B. coli* test, purer, and in respect of the *B. enteritidis sporogenes test somewhat less pure, than the water in the upper reaches* of the river at Sunbury and Hampton.

Apart from its chemical composition, and considered only in reference to bacteriological results, the water at Mucking was seemingly as fit for filtration and water-works purposes as at Sunbury and Hampton.

VI. At the Chapman Lighthouse, five miles below Mucking, the Thames water was so far improved relatively, as seemingly to vie in biological purity (*qua B. coli*) with some of the samples of filtered London water. About half the samples contained less than 1 coli-like microbe per c.c.

As regards the *B. enteritidis sporogenes* test, about four-fifths of *the samples from this section* of the river gave a positive result with 10 c.c. but a negative result with 1 c.c.

The alleged *gross* pollution *of the Essex and Kent* foreshores eastwards of a line connecting the Chapman Lighthouse with Stoke, as a result of the discharge of the Barking and *Crossness effluents into the* Thames, would thus appear from these data to be without sufficient warrant.

VII. The water obtained from the Barrow Deep was found to be, under the circumstances, remarkably satisfactory, notwithstanding the fact that 50,000 tons of sludge containing usually, according to results of the bacteriological examination, from 1,000,000 to 10,000,000,000 coli-like microbes per c.c., and from 10,000 to 100,000 spores of *B. enteritidis sporogenes* per c.c., were being deposited weekly in the Barrow Deep.

As regards coli-like microbes, the water here usually contained either 1 in 10 c.c. or 1 in 1 c.c. About half the samples contained spores of *B. enteritidis sporogenes* in 1 c.c., while about a third yielded a positive result with 10 c.c. but a negative result with 1 c.c. Broadly speaking, therefore, the Chapman and Barrow Deep results did not differ greatly as regards coli-like microbes.

The *B. enteritidis sporogenes test, however, yielded somewhat less* satisfactory results at Barrow Deep than at the Chapman Lighthouse.

It follows, therefore, that the alleged *serious* pollution of the Thames Estuary, *as a result of the deposit of sludge by the London County* Council in the Barrow Deep, is not supported by the results of the bacteriological analyses.

VIII. It is a point worthy of notice that, whereas at Barking, Crossness, Purfleet, and Grays, coli-like microbes were much more numerous than spores of *B. enteritidis sporogenes;* lower down the river the *B. enteritidis sporogenes* curve actually encroached on and in some instances overstepped the *B. coli* curve.

These results probably indicate that the decline in excremental bacteria in the lower reaches of the river is due not solely to sedimentation and dilution, but also *qua* non-sporing forms, *e.g.*, coli-like microbes, to destruction and death of these bacillary bodies.

IX. Finally, and taking a broad and common-sense view of the whole investigation, the following general inferences are perhaps warranted:

(a) That the water of a tidal river grossly polluted in its lower estuarial reaches may after a flow of some 25 miles become so far purified by sedimentation, dilution, and the operation presumably of bactericidal agencies, as to become seemingly as little objectionable, or in some respects less objectionable, bacteriologically than certain of our public water supplies.

(b) That the deposition in the sea of chemically precipitated sludge in enormous quantities, if carried out under proper conditions, need not result necessarily in the production of nuisance or serious pollution of the surrounding water, and that such deposition may be thought of as an economical and seemingly not unsatisfactory means of disposing of this material.

Effects of Dilution.—The following extract is taken from the Cantor Lectures on Bacterial Purification of Sewage, delivered by Dr. Samuel Rideal, D.Sc.Lond., F.I.C., before the Society of Arts, on the 16th January, 1899:—

"It is possible to form an estimate as to the amount of sewage which can be dealt with by a flowing stream, if one remembers that the bacteria, always naturally abundant in river water, are able by the aid of the oxygen dissolved from the air to consume more or less rapidly the organic matter. It is evident that the volume of the sewage and the oxygen required by the organic matter in it, as measured by permanganate, *i.e.*, the 'oxygen consumed,' should bear some relation to the flow of the river and its aeration. But, in addition to this, it is also desirable to take into account the amount of available oxygen, as nitrate and nitrite, since it has been proved that, always with the help of bacteria, the oxygen of nitrates and nitrites is available for the burning up of organic matter.

"From these factors the following formulæ may be deduced. Where X is the flow of the stream, O the amount of dissolved oxygen, S the volume of the effluent, M the 'oxygen consumed' by the latter, N the available oxygen, as nitrate and nitrite, C the ratio between the amount of oxygen in the stream and that which is required to oxidise the organic matter in the effluent, then the equivalent will be—

$$X\,O = C\,(M - N)\,S.$$

Where the sewage is fresh, and no nitrates have been formed—

$$X\,O = C\,M\,S.$$

If N be less than M, $M - N$ = the deficit of oxygen in the effluent requiring to be supplemented by the free oxygen in the river; such an effluent will throw a burden on the river, and cannot be considered in a satisfactory state, and it will be a question of volume and other circumstances whether it can be permitted to be discharged at all. This may be determined by the consideration that if the available oxygen of the river, $X\,O$, be greater than the demand $(M - N)\,S$, there will be a chance of the stream dealing with the inflowing liquid, but if the reverse be the case, foulness will necessarily accrue."

It should be pointed out in this connection that the effect of reduction of the organic matter in sewage by dilution with clean water is not quite the same as reducing the organic matter to the same degree by some oxidising process; the effluent under the latter condition would be better than the former; in other words, the effluent from the oxidising process would be less active in taking up oxygen or becoming putrefactive than the sewage brought to the same strength by dilution. This should be borne in mind when considering the question of storm overflows and the degree of dilution desirable.

Ratio of the Chlorine to the Total Nitrogen.—Dr. S. Rideal, D.Sc. Lond., F.I.C., in his Cantor Lectures, 1899, states (p. 37) that on many previous occasions he had pointed out that a "calculation of the *ratio* between the different forms of nitrogen furnishes a clearer idea of the history and character of an effluent than a mere consideration of its amounts." He draws attention to the fact that "besides the formation of free ammonia in the transition or preparatory stage, and the conversion into nitrite and nitrate at a later period, there is a considerable dispersion of organic nitrogen in the form of innocuous gases." Dr. Rideal claims to be "the first to propose an expression for the measurement of this important phase of the purification, obtaining the data from the *ratio of the chlorine to the total nitrogen*.

"In perfectly fresh excreta, taking the solids and liquids together, the total fixed nitrogen somewhat exceeds the chlorine. This proportion will remain unchanged when diluted with water containing only the ordinary small amount of chlorine, as long as the nitrogen remains in fixed forms.

"Therefore, the ratio is applicable to fresh sewages generally, independent of dilution, but will be immediately altered by the production of gas.

"Let Cl and N in the parts of chlorine and nitrogen respectively, the 'residual ratio' will be—

$$R = \frac{N \times 100}{Cl}$$

or, in case of great dilution, with a high chlorine W, in the water supply

$$R = \frac{N \times 100}{Cl - W}$$

"The simpler formula is usually sufficient. In the original excreta the number R will be somewhat over 100; in fairly fresh sewages it will be about 100; in bacterial effluents, on the other hand, the fall of R will indicate the gaseous dispersal of nitrogen. With chemical or mechanical treatment R will fall, owing to the abstraction of matter, as sludge. Where heavy nitrification has been the main feature, there may be little or no fall, this afterwards occurring rapidly in the process of *denitrification*, when the effluent is admixed with other water."

Dr. Sidney Barwise, M.D., M.R.C.S., etc., in his book *The Purification of Sewage*, referring to chlorine (p 16), says :—"The chlorine in sewage has its origin in common salt, of which it constitutes 60 per cent. It enters the sewage as salt in the waste from kitchens and in the urine. There is also a certain amount of chlorine in all drinking water. It is also present, to a slight extent, in rain-water. On the West

largely from wool scouring, large quantities of grease and fatty matter are contained in the sewage which, first of all, must be treated with sulphuric acid to crack the grease. In Burton-upon-Trent, where there is a large quantity of brewery refuse, special treatment has to be adopted.

The addition of the spent liquor from the sulphate plant of a gas works when passed into the sewers may if of sufficient volume have a deleterious effect upon the purification process.

At Sutton, in Surrey, the Gas Company in 1905 put down a sulphate plant, and turned their spent liquor into the sewers. The liquor itself was comparatively weak, containing an equivalent of 0·15 per cent. of ammonium sulpho-cyanide, and amounted in volume to about 3 per cent. of the total sewage flow.

The effect of this spent liquor upon the bacteria beds was at once apparent: the effluent became putrefactive and the medical officer on examination found that the beds were being sterilised. As soon as the liquor was prevented from flowing into the sewers the trouble ceased.

The Sutton Gas Company subsequently put down a purification plant for dealing with this liquor, and this plant has been so successful that no further trouble has resulted from the effluent.

Such cases as these must, of course, receive special consideration, and in a work of this nature it would be quite impossible to attempt even to suggest the possible treatment in such abnormal cases. As above stated, in all ordinary cases the combined domestic sewage and trade refuse can be treated by the processes which are applicable to domestic sewage alone, provided that the works are properly devised and of sufficient capacity.

The following figures illustrate the varying composition of sewage in parts per 100,000 :—

TABLE 100.

Town	Oxygen absorbed 4 hours	Total Solids
York	4·16	84·27
West Bromwich	5·03	159·4
Huddersfield	9·20	100·0
London, 1900	11·55	156·0
Leeds	11·8	178·6
Bradford	25·0	313·0
Hanley	5·02	170·9
Birmingham	26·64	47·8 in suspension
Yardley	11·30	90·5
Keighley	6·11	85·67

The following table shows the great variation in the sewage of the City of Manchester at different times :—

TABLE 101.

Date.	Oxygen absorbed 4 hours	Oxygen absorbed 3 minutes.	Ammoniacal N.	Albuminoid N.	Chlorine.
Crude Sewage.					
May, 1899.	5·99	3·37	2·33	0·324	16·0
June 2nd to August 16th.	6·54	3·80	2·47	0·370	16·1
Three months ending December 26th, 1900.	11·46	5·47	2·01	0·610	16·6
Six months ending December 26th, 1900.	11·11	5·19	2·23	0·590	17·0
Settled Sewage.					
Aug. 17th to Sept 13th, 1898.	6·43	3·64	2·28	0·294	16·0
Sept. 16th to Oct. 14th, 1899.	5·77	2·94	1·80	0·276	13·9
Year 1899.	6·75	3·62	2·30	0·330	16·0
Six months ending March 28th, 1900.	7·23	3·70	2·21	0·306	16·1
Six months ending December 27th, 1900.	7·86	3·93	1·91	0·335	16·3

Enough has been said to show that the raw material to be operated on at a sewage purification works may vary in composition within very wide limits in different localities, and at different times in the same locality even in dry weather. When the effect of the increased quantity due to rainfall is taken into consideration, it is small wonder that the sewage problem is one the solution of which cannot be determined once for all by any one system which shall be applicable alike to all towns.

Steps in the Process of Purification.—In almost all processes of purification the first step is to remove the matters in suspension, and this is usually effected by allowing the particles to settle by gravity in suitable tanks, or by precipitation by the addition of chemicals, or by liquefaction by bacterial action and settlement combined in a septic tank, or by assisting the latter actions by presenting large surfaces to attract the floating matter as in Dr. Travis' hydrolitic tank or Mr. Dibdin's slate filter. These processes all produce a greater or less quantity of sludge which must be subsequently dealt with; they will be referred to more in detail later, and are merely named here to indicate the general lines of the methods employed.

Having freed the liquid as far as possible of the suspended solids with their organic contents, the effluent from the first part of the process must be subjected to a further treatment, which has for its object the oxidization of the matters in solution, and their conversion into harmless inorganic compounds which will not putrefy or take up oxygen from the stream into which it may be intended to discharge them.

This part of the process may be effected by application to land or to

some form of bacterial filter, but if the latter it is usually necessary to have a further process for the removal of the solids in suspension which are evacuated by the filter; this can be effected either by land treatment, filtration, or settlement in tanks or lagoons.

By these means an effluent can be produced which will be chemically pure enough to pass the standards at present in use for chemical and bacterial purity for non-drinking water streams, but as to whether in the future effluents to be discharged into drinking water streams may not require some form of sterilisation for the removal of pathogenic organisms is a matter on which considerable doubt exists.

Dr. S. Rideal, in his book on "Sewage and the Bacterial Purification of Sewage," thus describes the steps in the process of purification, which he considers should be divided into three or four stages:—

—	Substances dealt with	Characteristic Products.
Initial.		
Transient aerobic changes by the oxygen of the water-supply, rapidly passing to—	Urea, ammonia, and easily decomposable matters.	
First Stage.		
Anaerobic liquefaction and preparation by *hydrolysis*.	Albuminous matters Cellulose and fibre. *Fats.*	Soluble nitrogenous compounds. Phenol derivatives. Gases, ammonia.
Second Stage.		
Semi-anaerobic breaking *down of the intermediate* dissolved bodies.	Amido-compounds. Fatty acids. Dissolved residues. Phenolic bodies.	Ammonia, nitrates, gases.
Third Stage.		
Complete aeration, oxidation and nitrification.	Ammonia and carbonaceous residues.	CO_2, H_2O, and nitrate.

Mr. W. J. Dibdin, in a paper read before the Association of Municipal and County Engineers in June, 1906, indicated the nature of the work involved in sewage purification by the diagram on p. 579.

He stated that to convert the organic substances into harmless inorganic matter a sufficient quantity of oxygen must be brought into combination with the nitrogen, hydrogen, and carbon, so as to form nitric acid, carbonic acid, and water, the agencies available for the separation and ultimate destruction of sewage matters being: (1) Gravity; (2) Biological action; (3) Oxygen; the two latter being interdependent.

Mr. W. D. Scott-Moncrieff, in a paper read before the Royal Sanitary

Institute in March, 1907, divided the breaking down of organic matter used as food into inorganic substances into three successive stages :—

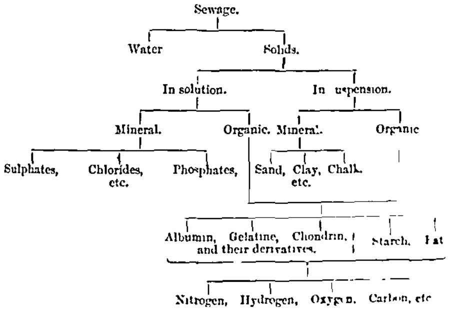
First, the changes which occur in the alimentary canal, which he considered to be almost exclusively confined to the action of anaerobic organisms.

Second, those due to putrefactive fermentation and liquefaction of solids caused by anaerobic bacteria.

And thirdly, the results obtained from the action of the nitrifying organisms or aerobic bacteria.

He considered that the ultimate purification in a sanitary sense could be obtained from either of the last two stages, but stated that in nature

MR W. J. DIBDIN'S DIAGRAM OF SEWAGE PURIFICATION



the second stage generally preceded the third and made the subsequent action of the aerobic organisms much more rapid and complete, but that the essential character of the completed cycle was that the organic matter contained in the sewage should be delivered to the organisms of nitrification free, as far as possible, from the presence of the organisms employed in the earlier stages and also from their enzymes or products.

On the other hand, Dr. Travis holds that the process of sewage clarification—*i.e.*, the removal of suspended matter—is in the main the result of physical operations and that bacteria play only a subsidiary part *in this part of the purification process.*

In a paper read by him, in conjunction with Lt. Col. H. S. Jones, V.C., before the Institution of Civil Engineers in 1905 * great stress

* Proceedings Inst. C.E., Vol. CLXIV., 1905.

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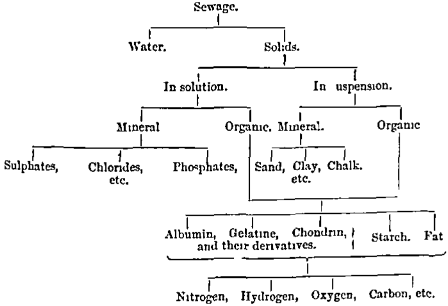

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is laid upon the elimination of the colloids in sewage, these being matters of a gluey nature in a state of extremely fine sub-division between the conditions of solution and suspension * ; and the opinion was expressed that in the case of the sewage of Hampton, if the suspended solids be removed by any preliminary treatment, then 59 per cent. of the remaining organic matter is in the colloidal state.

This view of the problem has become known as the Hampton Doctrine and can best be described by a quotation from a paper read by Dr. Owen Travis in July, 1908, before the Association of Managers of Sewage Disposal Works, as follows :—

The Hampton doctrine teaches that the purification process is essentially a physical operation, being, in its complete expression, a continuous desolution action. In other words, the suspended and soluble impurities contained in the sewage drop out of, or are, as solid or insoluble matters, absorbed from, that liquid as effectually as if they had been entirely removed by a process of precipitation, to which, indeed, the action is analogous. The doctrine asserts that the purification process is strictly a reversal of the collection and of the conveyance processes—that is to say, the gross solids and other fouled waste products from the house are discharged into the water supplied to the house, and are conveyed by it to the disposal works. On their way *thereto these matters are mechanically disintegrated, and more or less* intimately blended with the liquid. In the treatment area the solid substances are physically reflocculated, re-collected, and the clarified *liquid passes on. The fact that the liquid is not brought to its original* condition of purity does not in any way invalidate the truth of the *principle, but is the fault of the method, or, rather, is due to the* necessity *of* having *to* pass large *volumes of foul liquid through* comparatively open material in a limited area. The impurities are thus transferred from the house to the disposal works. These works, therefore, are essentially depots *for the reception* and *for the storage* of the solid matters which have been abstracted from the sewage, for that which was sewage is now, in virtue of a physical operation, a comparatively pure liquid which has passed on, having deposited its sludge in the treatment area. The doctrine thus denies that the purification process is, in any sense of the word or under any circumstances, the result of bacterial action. These micro-organisms are merely incidental, and their actions are but ancillary to the actual purification. The expression of bacterial activity is, though not entirely, yet practically limited to the consecutive operation upon the deposited and absorbed matters stored in the treatment area from

* Colloids are substances in solution which will not pass through a porous membrane e.g., starch, gum, albumen and gelatine.

sewages already purified. Moreover, in this subsequent operation the bacteria are but one of the many groups of scavengers engaged upon the conversion of animal and vegetable excrete and dead matters into their living equivalents or into substances on their way thereto. To this, the destructive part of the process, the word biolysis—to loosen or to break down by vital forces, or by the actions of organised beings—being the most comprehensive, is the most accurate.

The doctrine is also at variance with the accepted theory in regard to the condition in which a large proportion of the so-called solids in solution exist in sewage. The usual division of the sewage solids, as determined by the filter paper, into solids in suspension and solids in *solution* is wrong, and has given rise to many erroneous deductions. This will be elucidated by considering the sewage of Norwich. This sewage contains, on an average per 100,000 parts, 165 parts total solids. Of these, 68 parts deposit in two hours' quiet settlement, and may be accounted gross solids, capable of being removed by tank operations; 12 parts do not settle in that time, and are not depositable by ordinary tank operations, but can be arrested on a filter paper, and are as fine solids recorded with the 68 parts as the solids in suspension; 20 parts will not diffuse through a parchment membrane, and constitute the particles in colloidal solution; and the remaining 65 parts are the solids in actual solution. These two latter are usually recorded together as the solids in solution, but the colloidal solution solids are as definitely suspended as the fine and the gross matters above referred to, and ought to be classified with them as *solids in suspension*. More especially is this so, since these solids are reciprocally related to each other. For it must not be assumed that the 20 parts represent the sum of the colloids in the sewage, but only that they are expressive of those existing in colloidal solution, or in *fluid mixture*. A very large proportion of the fine solids, and no inconsiderable proportion of the gross solids, are also colloid bodies, existing in the condition of *solid mixtures* of fluid and solid. The remaining colloid condition—the *solid form*—of which glass is the typical illustration, does not exist, excepting adventitiously, in sewage.

The intimacy of relationship above referred to is rendered evident by remembering that colloid bodies which are amorphous substances, pass, more or less readily, from an obviously particulate to an apparently liquid condition, as well as the reversal of this operation, from a condition of solution to a liquid containing definite suspended matter. The important characteristic of colloidal solutions is that they consist of infinitesimally fine particles, held in suspension and disseminated throughout the entire body of liquid. The particles can be separated from the liquid in a moment by passing an electric current through it,

or by adding a chemical precipitant to it. The particles will also separate out from the liquid spontaneously within a variable period of time, in virtue of the tendency of the organic colloidal solution solids to flocculation.

Dr. Travis has designed a special form of tank which has for its object the removal of the colloidal matter. This tank will be referred to and described in the next chapter (p. 638); it is mentioned here only to indicate the differences which are still held with regard to the processes which are necessary for the complete solution of the problem of sewage purification.

The final settlement of this question is one which lies more in the domain of those who are devoting their time to the scientific side of the question, viz., physicists, chemists, bacteriologists and medical men, than in that of the engineer.

The function of the latter, whilst taking an intelligent view of the work of his scientific colleagues, is not to attempt to settle these matters for himself, but, having obtained the views of those qualified to carry out original research, to design works which shall give a practical expression to the results obtained by the workers in the laboratory.

This work is written by an engineer for the use of engineers, and it is not proposed to discuss this branch of the question further, but having indicated the problem to be performed and the general broad outlines of the steps necessary to be taken to secure the desired end, to proceed now to give an idea of the degree of purification expected by setting out some of the standards of purification which have been suggested.

Standards of Purity.—There has been much controversy as to the desirability of setting up a standard of purity to which all sewage effluents should be reduced, but there are very obvious difficulties to be faced in undertaking such a task.

Apart from the great variation in the strength of the sewage to be purified, and the divergence of opinion *as to what may in the future be* recognised as a practicable degree of purity, the nature of the water into which the effluent has to be discharged presents the greatest difficulty. This may be—

(1) The open sea.

(2) A land-locked harbour.

(3) A tidal estuary.

(4) A tidal river.

(5) A river not used for drinking water.

(6) A river used for drinking water.

(7) A small watercourse, *almost dry at times*, and flowing through a populous district.

It will be at once apparent that to ask all sanitary authorities to purify their sewage to an equal degree, without reference to the quantity or quality of the water into which the effluent would be discharged, would be to inflict an injustice on some one, and therefore, whatever standards may be set up, they will have to be applied with some discrimination.

In order to give readers an indication of the different views held on this subject, the following information as to the alleged provisional standards of certain well-known authorities is given. This information is put forward with a certain amount of reserve, as, with the exception of the Rivers Pollution Commission, 1868, the authorities have not so far as the author is aware published any official statements as to what their standards are.

Standards of Purity recommended by the Rivers Pollution Commission, 1868.

"We now recommend that the following liquids be deemed polluting and inadmissible into any stream :—

(a) "Any liquid which has not been subjected to perfect rest in subsidence ponds of sufficient size for a period of at least six hours, *or* which, having been so subjected to subsidence, contains in *suspension* more than one part by weight of dry organic matter in 100,000 parts by weight of the liquid, *or* which, not having been so subjected to subsidence, contains *in suspension* more than three parts by weight of dry mineral matter, or one part by weight of dry organic matter in 100,000 parts by weight of the liquid.

(b) "Any liquid containing, *in solution*, more than two parts by weight of organic carbon or ·3 part by weight of organic nitrogen in 100,000 parts by weight.

(c) "Any liquid which shall exhibit by daylight a distinct colour when a stratum of it one inch deep is placed in a white porcelain or earthenware vessel.

(d) "Any liquid which contains, *in solution*, in 100,000 parts by weight, more than two parts by weight of any metal except calcium, magnesium, potassium, and sodium.

(e) "Any liquid which, in 100,000 parts by weight, contains, *whether in solution or suspension*, in chemical combination or otherwise, more than ·05 part by weight of metallic arsenic.

(f) "Any liquid which, after acidification with sulphuric acid, contains, in 100,000 parts by weight, more than one part by weight of free chlorine.

(g) "Any liquid which contains, in 100,000 parts by weight, more than one part by weight of sulphur, in the condition either of sulphuretted hydrogen or of a soluble sulphuret.

(h) "Any liquid possessing an acidity greater than that which is produced by adding two parts by weight of real muriatic acid to 1,000 parts by weight of distilled water.

(i) "Any liquid possessing an alkalinity greater than that produced by adding one part by weight of dry caustic soda to 1,000 parts by weight of distilled water.

(k) "Any liquid exhibiting a film of petroleum or hydrocarbon oil upon its surface, or containing in suspension, in 100,000 parts, more than ·05 part of such oil."

Mersey and Irwell Joint Board.

Albuminoid ammonia........................	0·14	parts per	100,000.
Oxygen absorbed in 4 hours at 60° F. ...	1·43	„	„
Oxygen absorbed in 3 minutes at 60° F.	0·36	„	„
Solids in suspension	4·3	„	„
Incubator test 3 to 5 days at 75° F.			

West Riding of Yorkshire Rivers Board.

When nitrates are absent.

If the oxygen absorbed in 4 hours at 80° F. is below 0·5 part per 100,000 the sample is considered good.

From 0·5 part to 1·0 the sample is considered fair.

From 1·0 part to 2·0 the sample is considered unsatisfactory.

Over 2·0 parts the sample is considered bad.

When nitrates are present in amounts of 0·1 or over.

If oxygen absorbed in 4 hours at 80° F. is below 1·0 part per 100,000 the sample is considered good.

From 1·0 to 2·0 parts per 100,000 the sample is considered fair.

From 2·0 to 2·5 parts per 100,000 the sample is considered unsatisfactory.

Over 2·5 parts per 100,000 the sample is considered bad.

Solids in suspension not to exceed 4 parts per 100,000.

Ribble Joint Committee.

Albuminoid ammonia if under 0·1 part per 100,000, effluent good.

Albuminoid ammonia if under 0·15 to 0·2 part per 100,000, unsatisfactory.

Albuminoid ammonia if over 0 2 part per 100,000, bad.

Solids in suspension 3 parts per 100,000.

Thames Conservancy Board.

Organic carbon 3 parts per 100,000.

Organic nitrogen 1·1 parts per 100,000.

Derbyshire County Council.

A sewage effluent should be clear and bright, without suspended matter, and on shaking vigorously it should not froth.

It should conform to the following tests :—

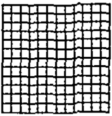
(1) *Shake Tests.*—A simple test of purity can be readily applied. It is, to shake vigorously for one minute a bottle half full of the effluent. All frothing should disappear in three seconds.

(2) Tests of opacity from suspended matter :—

The effluent should be so transparent that "Pearl" type can be read by a normal-sighted person through a column 12 inches in depth. (The type below will illustrate this test.)

A similar test has been devised by Dr. Reid, and consists of measuring the column of effluent which is necessary to obliterate the lines on the block shown below.

A good effluent will permit of the lines being distinctly seen through a column 12 inches in depth.



Pearl type as a test of freedom from suspended solids

(3) Albuminoid ammonia.

On chemical analysis an effluent should yield less than 0·1 part per 100,000 of albuminoid ammonia. This amount of albuminoid ammonia is taken as index of nitrogenous organic matter which remains unoxidised into nitric and nitrous acids, and is not split up into other harmless products.

not absorb more oxygen from potassium permanganate than it did before incubation. This test is generally known as the "Incubator Test," and is one which is now being generally adopted with effluents.

All these standards are based upon chemical data and do not take into consideration the bacteriological character of the effluent. When the Royal Commission on Sewage Disposal, 1898, commenced their investigations it became necessary for them to have a standard by which to compare the characters of the sewages under their observation.

For this purpose, and as working standards only, Dr. A. C. Houston, the Bacteriologist to the Commission, drew up the following:—

In the case of *drinking-water streams*, partial sterilisation, the destruction of *B. coli* to the extent of securing absence in 1 c.c. of the effluent being taken as satisfying such standard. Complete sterilisation of sewage effluents would not seem to be a practical measure, otherwise this higher standard would be recommended.

As regards *non-drinking water streams, provisional standards and for working purposes* only. For the chief tests employed they are as follows:—

Total number of bacteria.	Gelatine at 20° C.	Less than 100,000 per c.c.
	Agar at 37° C.	Less than 10,000 per c.c.

B. coli, less than 1,000 per c.c.

B. enteritidis sporogenes test and "Gas" test (24 hours at 20° C.)	Negative results with 0·1 c.c.
Indol test (5 days at 37° C.) Neutral-red broth test (2 days at 37° C.) Bile-salt broth test (2 days at 37° C.) Litmus milk (modified) test (2 days at 37° C.)	Negative result with 0·001 c.c.

These are primary standards; secondary standards are arrived at by rendering the primary standards ten times more lenient.

It may be asked: Is it not possible to reject artificial processes of sterilisation and apply the above same tests, but with more stringent standards, to the case of drinking-water streams? The answer for obvious reasons is in the negative, from the epidemiological point of view; but from the practical standpoint it may be said that *relative* safety would *probably* be secured by making effluents destined to discharge into drinking-water streams, the above standards one hundred times more stringent.

With regard to tidal estuaries, Dr. Thresh, M.O.H. for Essex county, has suggested as a standard that the sewage shall never exceed in volume 1 per cent. of the tidal water.

For the use of engineers making an inspection of sewage effluents or polluted streams the tests Nos. (1) and (2) of the Derbyshire County Council are recommended as easily applicable in the field, and they can

be augmented by a search for sewage fungus (see Appendix II.), the presence of which in the effluent channel or stream is a sure indication of sewage contamination. If these standards are satisfactorily passed a rough incubator test may be made by placing a sample of the liquid in a clean stoppered bottle and keeping it for four or five days in a warm room. If at the end of that period the liquid, on being shaken, gives off no offensive smell, the effluent may be considered satisfactory in ordinary circumstances.

be quoted as an example of this method of sewage disposal; the sewage of Hull and Grimsby and, higher up, of Goole is quite lost in the large quantity of tidal water daily flowing into the estuary. The Mersey again receives the sewage of Liverpool, Birkenhead and adjoining urban authorities without detriment, as does the Tyne at Newcastle and Gateshead.

In other estuaries where the flow of sea water is not as large in proportion to the sewage it is necessary to provide a more or less efficient system of precipitation to be carried out before the sewage is discharged. The Thames is a well-known example of this method of disposal, and the sewages of Dublin, Southampton and other places are precipitated before being turned into their respective estuaries.

In two recent cases, namely, at Southend-on-Sea and Southport, where the final effluent is disposed of in the open sea, complete systems of purification have been adopted prior to the discharge into the sea.

Land Treatment.

Detritus and Screening Tanks.—In every sewage purification works the first step of the treatment should be the removal of the heavy road detritus and mineral matters in suspension and the large floating matters. This is effected by passing the sewage through a detritus and screening tank: it is at this point that the separation of the three volumes of dry-weather flow of sewage, and rainwater from the surplus diluted sewage usually takes place, and the tank can easily be designed with a long weir over which the surplus can flow without raising the water level and so backing up the outfall sewer.

The detritus to be removed, although said to be in suspension, is chiefly sand and grit, which in most cases is rolled along the invert of the outfall sewer, and can be separated from the liquid very easily by reducing the velocity of the latter and providing a receptacle into which the sand, etc., can drop. In the case of sewers with a very high velocity the detritus may be churned up into the body of the liquid, and in such cases the separation will be more difficult than in slower moving sewage. The floating matter consists of paper, fibre, solid excrement, etc., and can be removed by screens or strainers.

Considering the importance of this part of the process of sewage purification very little thought appears to have been given to the design of either the tanks or the screens for removing the floating matters, and great variations both in form and size are found in practice.

The tanks should be large enough to reduce the velocity of the sewage sufficiently to deposit the heavy grit, and therefore regard should be paid to the gradient of the outfall sewer; on the other hand,

is extended between two rollers, one at the bottom of the tank and the other above top water level. The upper roller is rotated by power which, in the case shown, is supplied by a waterwheel driven by the sewage. A rotary brush driven in the reverse direction to the screen roller brushes the screenings into a hopper or trough.

Fig. 3, Plate XLVI., opposite, shows another form of moving screen made by Messrs. James Watt & Co., of Birmingham, for the Rothwell sewage works described p. 729. In this machine the sewage is delivered on a perforated horizontal disc with perforations $\frac{1}{14}$-inch diameter. The disc is rotated by power through a central spindle, and is cleaned by a gutta-percha squeegee placed upon an iron arm at such an angle as to sweep the screenings into an iron box from which they are removed by hand.

An apparatus for very fine screening is in use at the Leeds Sewage Works with 30 meshes per square inch. The screening surface is inclined, the rush of sewage washing forward the matter screened off. The sewage passes through a tipping trough or box which when full turns the contents over on to the screen about every ten seconds, and this effectually washes forward the screenings and gives the screen time to clear itself of liquid.

Another form of screen is also devised at these works in which a brush is automatically drawn across the screen by the sewage itself falling into a tipping bucket, and the brush pulled back to its original position by a counterpoise weight.

Fig. 4, Plate XLVI., opposite, shows another form of screen made by John Wolstenholme.

The screen is framed in cast iron, filled in with wedge-shaped steel bars and fixed at an inclination in the catch-pit. Rakes attached to endless chains actuated from above remove the screenings and convey them to a wooden tray attached to standards. The top framing consists of cast iron standards with steel cross bar. Adjusting screws are provided to tighten the chains. The rakes can be worked by hand or by power.

Fig. 5, Plate XLVI., opposite, shows a type of sludge elevator manufactured by Messrs. Ham, Baker & Co., Ltd., for installation in large sewage disposal works.

distance above the floor line to allow of wagons being placed under it to receive the detritus.

The capacity of a machine of the type shown provided with buckets 18 inches wide is from 15 to 20 tons per hour.

Suitable speed reduction gearing is provided and adjustable blocks to take up the stretch and wear of the chains.

Selection of Land.—When selecting land for sewage purification purposes, the question of the position of the land in relation to the town and the relative advantages of alternative sites at different distances often have to be decided.

Within moderate limits the general feeling is that the further the sewage can be taken away from the community the better, but this must obviously be governed by levels, suitability of land, and cost of outfall sewer.

The arguments in favour of being at a distance are :—

(1) Sentimental, if not health, considerations for treating sewage as far away from populated districts as possible.

(2) Land is likely to be cheaper in rural than in suburban districts.

(3) There is less likelihood of difficulty arising in obtaining additional land for future extensions.

(4) A long outfall sewer acts like the fly wheel on an engine, and tends to equalise the quantity and quality of the sewage.

(5) During the passage of the sewage through the long sewer, the floating solids become disintegrated and partially liquefied by septic action.

On the other hand there are the following disadvantages :—

(1) The solid fæcal matter and cellulose matters, which have a clogging tendency, pass on to the land with the liquid, whereas with fresh sewage it is not difficult to screen out much of the solid fæcal matter and paper and to sell it to farmers or use it on the farm.

(2) If settling tanks and precipitation methods are in operation the sludge is apt to be of small market value, and is not readily disposed of.

(3) The longer the outfall sewer, the greater the first cost and the maintenance charges.

(4) The longer the outfall sewer, the greater the risk of percolation of subsoil water which has to be put on the land and thus becomes a burden.

Surplus Land.—The area of surplus land which should be attached to a sewage farm is a matter which may be of considerable importance, especially if the land under sewage is cropped, because as cereals are, practically speaking, inadmissible on an irrigable area, the crops ought to be of a kind (*e.g.* rye-grass) capable of being heavily sewaged and readily disposed of when cropped.

There is frequently an economical advantage in using the surplus area as a dairy farm and feeding the stock with the produce of the irrigable area, especially in those cases where there is a difficulty in disposing of crops.

This additional land, however, involves additional capital expenditure, the investment being of a somewhat speculative character.

The surplus acreage (*i.e.*, acreage in excess of the total irrigable area) varies in different cases from 10 per cent. of the total up to 50 per cent., and averages about 25 per cent.

Whilst it is impossible to lay down any rule as to the ratio of the surplus to the total acreage, it is desirable to have a large surplus, and, if possible, that this land should be so placed as to admit of the possibility of its being laid out for irrigation purposes if required.

Irrigation and Filtration.—The application of sewage to land is carried out by two processes, which are known as *broad irrigation* and *downward filtration*.

Where the land utilised is of a retentive character with a clay subsoil, broad irrigation is adopted, the sewage being distributed over the land in such a manner that it runs over the surface, and the purification is effected by the nitrifying organisms in the surface soil.

On the other hand, where the nature of the soil is open and porous with a sandy subsoil, the sewage is applied in such a way that it percolates downwards through the subsoil to the under-drains, and the land is used after the manner of an ordinary sand filter.

Land to be used for broad irrigation is frequently not drained at all, whereas in a filtration area under-drainage is essential unless the subsoil consists of very deep sand free from water, or an open fissured rock such as chalk. As, however, it is found desirable in some cases to under-drain irrigation areas to assist in the drying off process, a certain amount of downward filtration may take place, and it is therefore impossible to draw a distinct line between the two processes in every case.

In both broad irrigation and downward filtration it is desirable to intercept some of the solids in suspension in the sewage before applying the liquid to the land.

In sewage farming proper, the preliminary treatment is very slight, and usually consists of straining and rough settlement.

On the other hand, land is often used in conjunction with processes in which an effective preliminary treatment takes place, and the subsequent application to land is then carried out as a secondary part of the process. The area of land required for the two systems is totally different; roughly speaking, the sewage from 100 to 100 persons per acre can be treated on a sewage farm, whereas with an effective

preliminary process the sewage from 500 to 1,000 persons may be treated upon an acre of suitable land.

In dealing with this section of the subject it is assumed that land treatment is the main process and that the preliminary settlement will be very slight.

Removal of Suspended Solids.—The more effectually the solids in suspension in the sewage are removed, the less difficulty is experienced with the clogging of the surface of the land, particularly in the case of irrigation areas where the soil is of a clayey and retentive nature.

About two hours' sedimentation is usually sufficient to settle out the grosser suspended solids. Assuming that the maximum rate of flow in the middle of the day is about double the mean flow, this means that one-sixth of the mean flow would give a tank capacity sufficient to give the required degree of sedimentation.

As it is usual to construct tanks in duplicate so that during cleaning operations the sewage can be effectually settled with one tank out of operation, the total capacity of tankage provided on small farms should amount to about one-third of the mean daily flow, and this capacity would give sufficient storage to deal with the storm-waters as they may be delivered at the disposal works.

On large works the number of tanks may be increased so that one tank can be cleansed without throwing 50 per cent of the tank capacity out of operation. In such cases the total capacity may be proportionately reduced.

Although the above proportion of tank accommodation is that which theoretically should be provided, numerous instances of sewage farms will be found in which the tankage is considerably less, and in some cases is totally absent. Usually not more than half the above tank capacity is provided.

The *solids in suspension* may be removed by means of—

(1) Continuous settlement.
(2) Quiescent settlement.
(3) Upward filtration.
(4) Precipitation by the addition of chemicals.
(5) Septic tanks.

The following are the average results obtained with the sewage of a large city, one third of the volume of which is trade refuse :—

Total suspended solids	42 grains per gal.
After ½ hour's settlement .	17 " "
" 1 " " . .	12 " "
" 1½ " "	11 " "
" 2 " "	11 " "

This shows that quite a short period of settlement throws down more than half of the suspended matter, but that beyond one hour the settlement is very slow unless chemicals are used to assist precipitation.

Where the tanks are used on the continuous principle the sewage is continually running in at one end and out at the other over a wide sill.

In the case of tanks worked on the quiescent system the sewage is run into a tank and allowed to stand for from one to two hours, and the liquid is then decanted by means of floating arms.

The quiescent tanks require a fall of several feet to enable them to be emptied, failing which the sewage must be pumped, whereas continuous tanks require only a few inches of fall to enable the sewage to travel through them. Continuous tanks cost less to construct and are more economical in labour for attendance, and are therefore usually adopted in preference to quiescent tanks.

Rectangular tanks are usually made with floors sloping from each side to a central channel and the channel sloping from the outlet end to the inlet end. The greater part of the solids are deposited near the inlet, that is, at the deep end, and the above described form of floor facilitates the gravitation of the sludge towards the outlet valve.

The floor of circular tanks is generally made to slope towards the centre by an inverted cone, and in rectangular tanks the floors can be treated on the same plan by making two or more inverted pyramids; in both forms of tanks the sludge can be removed by pipes by gravitation if sufficient fall (about 3 or 4 feet) below the top-water level is available, or in the absence of this amount of fall by pumping.

The Dortmund tank (Plate XLVII., opposite), so called because it was first used at Dortmund in Germany, is worked on this principle The tank is cylindrical for part of its depth, with a conical bottom.

The sewage passes down a vertical pipe to the bottom of the cylindrical part of the tank, the pipe being fixed on the axis of the tank. The pipe is provided with radial arms to distribute the sewage evenly over the sectional area of the tank. The sludge settles to the well at the apex of the cone and is pumped out as it accumulates through a suction pipe led down inside the inlet pipe to near the bottom of the tank.

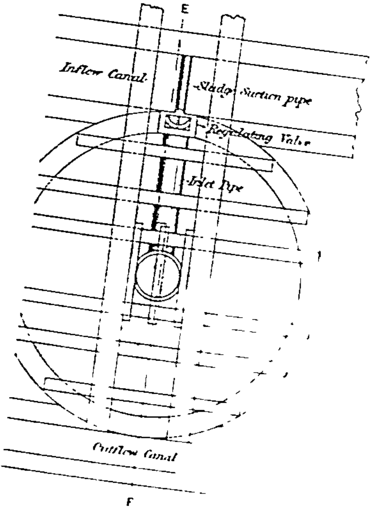
The effluent is drawn off by troughs so arranged as to sub-divide the surface equally and thus avoid setting up a current. The flow is kept at a uniform rate of 15 feet per hour, but this is probably too high a velocity to get good results.

This form of tank is not protected by patent and has been largely used. The chief defect is the danger of the sides becoming coated with sludge; this can be remedied by providing a revolving arm fitted with a squeegee to brush the walls.

The importance of designing tanks in the best manner to facilitate

PLATE XLVI

PLAN OF TOP



Irrigation Farms.—In irrigation farms it is usual as far as possible to apply the sewage to two, and sometimes three, or even four plots of land in succession, the sewage, after having been run over one plot, being picked up by a carrier running along the bottom of the plot. The effluent is then re-treated over other plots.

The distribution of the tank effluent over the surface of the land is effected by carriers. The carriers are from 12 inches to 2 feet or more wide, and are constructed with a fall of 1 in 500 to 1 in 1,000, of brickwork, concrete, or stoneware, and are usually open at the top. Pipe carriers are also used, but are not recommended, as the fall available is generally insufficient to make them self-cleansing. The subsidiary carriers may be made with half pipes or grips cut in the ground at suitable intervals of 10 to 20 yards apart running down the plots following the greatest fall.

Plate XLVIII., opposite, gives details of the construction of carriers. Figs. 1 and 2 are plan and section respectively of a large size carrier. Fig. 3 gives section of a stoneware carrier of large size. Fig. 4 is a section of an ordinary stoneware half pipe carrier. Figs. 5 and 6 are plan and elevation of a junction block on a carrier like Fig. 4, with sluices for discharging sewage on each side. Fig. 7 is a stoneware sluice valve for fixing in a concrete carrier.

The land between the plough cuts is inclined at falls varying from 1 in 20 to 1 in 150, depending upon the porosity of the soil, to furrows about midway between the plough cuts. The furrows, however, should be stopped before reaching the bottom of the plot, otherwise the sewage reaches too easily the pickup carrier which is run along the lower edge of the plot.

Where the land has an easy natural fall the distribution and pickup carriers can be laid as contours, and the distribution of the liquid between them can be made from frequent openings in the distribution carriers, these openings being controlled by shuttles.

The greater the number of carriers the better the distribution, but permanent carriers interfere with the cultivation of the land, and this limits the number which can be put down.

Carriers should be frequently cleansed, and any sludge deposits should be thrown well away from the carriers, as otherwise the land near them soon gets clogged by the solids brought down by the sewage.

The management of the rotation in which the sewage is applied to the land varies very widely in practice and largely depends upon the nature of the land and the views of the farm manager. In some cases the sewage is applied to the land for a few hours only and is then shifted to other plots for three or four days before being applied to the same land again. In some cases the period of application is extended to

TABLE 102.

Subject.	Beddington	South Norwood	Leicester	Rugby.
Character of soil.	Gravelly loam over gravel and sand.	Clay soil on London clay	Stiff clay on dense clay.	Heavy loam on stiff clay.
Character of sewage.	Domestic	Domestic.	$\frac{3}{4}$ domestic. $\frac{1}{4}$ trade.	Mainly domestic
Preliminary treatment	Screening and slight settlement.	Screening and settling tanks.	Screening and settling tanks.	Screening and settling tanks.
Proportion of irrigable area irrigated at one time.	$\frac{1}{6}$	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{7}$
Population per acre irrigated.	238	138	146	171
Gallons of sewage per head per day.	40	28·5	38·6	50
Gallons of sewage (exclusive of storm-water) treated per acre per day on area under irrigation at one time.	57,100	12,000	21,500	42,800
Gallons of sewage treated per acre per day on assumption that each acre of irrigable area is under sewage all the time.	9,500	4,000	5,370	8,700
Results of observations.	Too great a volume of even a medium strength sewage to be treated on even such a porous soil. Volume of sewage applied per working day very large owing to resting area being five times working area. Considerable volume of storm-water dealt with.	Possibly too large a volume of even a weak sewage on such a soil. Difficulty of storm-water must be great	Volume rather too large of a mixed sewage of moderate strength to be treated on soil of above nature. Farm does not deal with much storm-water.	Volume too large of a strong sewage to be treated by irrigation on such a soil. Large proportion of storm-water

very wide limits, depending upon the nature of the land, the strength of the sewage, the proportion of trade refuse or subsoil water, and other considerations. The number usually considered to be reasonable is from 100 to 200 persons per acre.

The Royal Commission on Sewage Disposal, appointed in 1898, had under observation for a long period four sewage farms in which broad irrigation is practised, namely Beddington (Croydon), South Norwood (Croydon), Leicester and Rugby, and the particulars in these four cases are given in Table 102, on p. 600.

From these particulars it will be seen that the population per acre except in the case of Beddington, which was overworked, lies within the limits previously mentioned, namely from 100 to 200 persons per acre, and in the case of Beddington the soil is gravelly loam, and a part of the area is used for filtration. The quantity of sewage in gallons treated upon strong clay land in these four cases lies between the limits of 1,000 and 9,000 gallons per day per acre, the results obtained being moderately good but not altogether satisfactory.

Leicester Sewage Farm.—As a good example of a strong land sewage farm used for irrigation process, the Beaumont Leys Farm of the Leicester Corporation may be taken, and the following details have been extracted from the particulars supplied to the Royal Commission on Sewage Disposal.

The soil of the farm is clay, the surface soil over the greater portion being of a stiff clayey nature, 6 to 12 inches deep, with a subsoil of from 2 feet 6 inches to 3 feet of yellow clay overlying a hard boulder clay and the Keuper marl.

The total area of the farm is about 1,700 acres, of which about 1,350 acres are under irrigation, the average area actually in use at one time being about one quarter of the total irrigable area.

The population draining to the farm in 1899 was 197,000, and the dry weather flow of sewage amounted to 7,250,000 gallons per 24 hours, or 37 gallons per head, made up of the following :—

Domestic Sewage . . .	$3\frac{3}{4}$ million gallons
Trade Refuse.	2 " "
Well and Subsoil Water .	$1\frac{1}{2}$ " "
Total	$7\frac{1}{4}$ million gallons.

The trade refuse was principally from wool scourers and fellmongers. The manufacturers are required to arrest solids by settlement in catchpits before discharging the waste into the sewers.

The population dealt with per acre of land irrigated was 146, and the quantity of sewage treated per acre per twenty-four hours, assuming

that each acre of irrigable land was being sewaged at the same time, was 5,370 gallons. Since, however, only one quarter of the area is under irrigation at the same time, the quantity actually treated amounted to 21,500 gallons per acre per day.

The sewage on arrival at the works is screened and passed through settling tanks, the capacity of which is rather less than 10 per cent. of the normal dry weather flow. These tanks are worked on the continuous system, and no chemicals are used, and they are cleaned out about once in three weeks by means of steam-driven chain pumps.

The tank effluent is taken along main carriers, provided with sluices at intervals, and is then turned on to the land, or into subsidiary carriers.

The method of irrigation is to send the tank effluent over one arable field, and then over one or more pasture fields. The sewage is applied to the land for long periods, from seven to fourteen days without a rest.

In preparing the arable land steam cultivation is resorted to in addition [illegible]

up the hard pan caused by the horses' feet in ordinary ploughing, and enables the land to subsequently take larger quantities of sewage.

The crops consist of roots, wheat, mangolds and oats, but rye-grass constitutes the principal crop.

Nearly all the mangolds are consumed on the premises, the rye-grass is used on the farm and for the Corporation horses, and a large herd of bullocks are kept on the farm. They are allowed to feed on the irrigated land, and are said to do considerable damage by treading in the soil and forming pools, in which the sewage stagnates.

There are about 350 acres of land not sewaged, on which the cattle can be kept when it is not desirable to put them on the irrigated land. It is not the practice on this farm to irrigate growing crops except in the case of permanent pasture and rye-grass, and, to a small extent in dry weather, mangolds.

Beddington Irrigation Farm.—Plate XLIX., p. 604, is a plan of Beddington Irrigation Farm, Borough of Croydon, Surrey.

The drainage area flowing to this farm is about 6,300 acres, and the population to it about 127,000.

Part of the sewage, on its way to the farm, passes through a revolving screen at Brimstone Barn. About 2 cubic yards of solids per day are taken out by this operation.

There are two outlets of sewage on to the farm, one from Croydon and the other from Thornton Heath and Upper Norwood. The dry-weather flow varies somewhat with the height of the sub-soil water in

Croydon Valley, but it may be put at 4,250,000 gallons in twenty-four hours.

The sewage flows on to the farm from both outlets by gravitation.

About three-quarters of the roads in the drainage area have surface water drains in them, with which the road-gullies are connected, and they discharge into the River Wandle and Norbury Brook. Still, the volume of storm-water entering the sewers is occasionally very great, and several times a year it may be put at the rate of 16,000,000 gallons in twenty-four hours. There is no storm overflow in any shape or form, and the whole of the storm-water entering the sewers is delivered on the farm. There, in order to cleanse it, it is sometimes run over all the grass land, and other plots as well, to the injury of the crops.

The area of the farm is 694 statute acres; about 500 acres are laid down for broad irrigation, the remainder being occupied by farm buildings, cottages, strips of land alongside roads, and high ground. Thus the drainage of about 254 persons is cleansed on each acre, but it should be noted that about 1,000,000 gallons are treated daily upon sprinkler beds, and considerable additions of artificial works are being carried out.

The farm overlies the Woolwich and Reading beds, and the subsoil is chiefly of gravel (very open in some places) and sand. The soil varies considerably, from loam to a light, free, open soil, but all is very suitable for irrigation. The aspect of the farm is a gentle slope from east to west, averaging about 1 in 210. The farm is compact, the upper side of it being about 1,000 yards from the nearest occupied part of the Borough of Croydon, and the outlet side about 450 yards from the River Wandle, into which there are two outlets for the effluent water.

Irrigation on part of the farm was begun in 1860, and has since been continuous. There was no under-drainage until 1883, and now about 120 acres have drains, generally very wide apart, and from 4 to 9 feet deep, varying in diameter from 4 inches to 2 feet. Although these do not assist in cleansing the sewage, yet they help to quicken the drainage of the land after the sewage is taken off it.

The ground naturally lying with a very even fall towards the Wandle, the only operation required was to adjust the surface to suit the carriers, raising some places and lowering others, but so little that still a proper thickness of soil was left for cultivation.

The bringing-on carriers at the top of the plots are usually of concrete, from 2 to 4 feet wide and level as long as the ground permits.

If at any place it is necessary to have a drop this is done by means of a wooden sluice.

Small trenches are made with the plough from the bringing-on

carriers down the greatest fall, at a distance from each other of about 50 feet. The ground is a little lower between these trenches to make the sewage spread over the entire surface. Movable galvanised iron or wooden stoppers are used to divert the water at varying distances down the trenches. These trenches end about 40 yards from the bottom of the plots where the hollowing ceases, the ground is thus level across, so that the whole breadth of land is irrigated. A pick-up carrier runs along the bottom of the plot, over the edge of, and into which the effluent water passes. The system in use is that of surface or broad irrigation; and, as a rule, the sewage passes over three separate portions of the farm. It first passes over one portion, which is covered with it; from thence the sewage, partially purified, flows to a second portion of the farm, and then to a third, from which it passes in a pure state. *The time occupied in passing over the farm is about three* hours. It is estimated that 2 out of every 3 gallons of sewage pass off the farm as pure effluent water, the other gallon being either evaporated or absorbed by the land and the growing crop. The colour of the Italian rye-grass indicates exactly where it has been irrigated; and when ready for cutting the crop should have a uniform dark-green appearance.

There is no difficulty in cleansing the sewage in the severest frost. The practice is to flow it over ploughed land that will be sown with mangold, and also over the worst rye-grass plots. Ice is formed on the surface, but the sewage flows underneath it, and the purification still goes on, although it requires more area, and the effluent may not be quite so good as at other times.

The following is about the average cropping of the irrigated portion of the farm :—

Rye-grass	400	statute acres.
Old pasture	40	„
Mangolds	60	„
Total ..	500	„

Rye-grass, the principal crop, exhausts itself in about three years, when it is ploughed up and replaced by a crop of mangold or cabbages, followed occasionally by a crop of wheat, oats, or potatoes, and then a return to rye-grass. Five heavy crops of the latter are usually grown in a season. The mangolds also are a heavy crop. Wheat and oats are grown chiefly for the straw, which is very strong, and, in consequence, usually laid before the grain is ripe; the expense of weeding and taking garden produce to market militates against its growth on this sewage farm.

PLATE XLIX.

[...]ORATION OF CROYDON.

PLAN OF

[...]GTON IRRIGATION FARM.

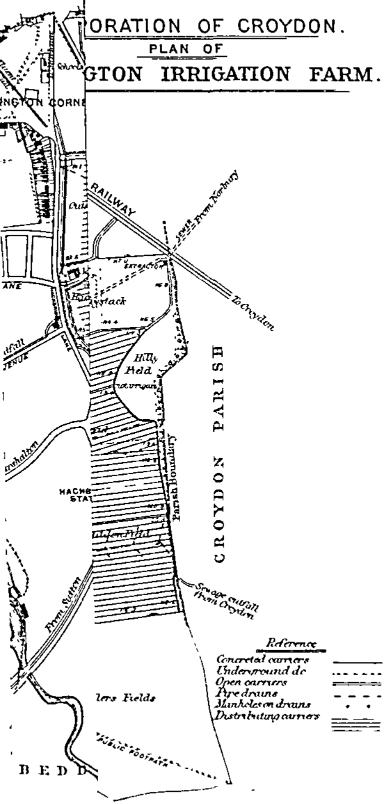


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PLATE XLIX.


ORATION OF CROYDON.
PLAN OF
GTON IRRIGATION FARM.
RAILWAY
Sewer from Norbury
To Croydon
Hilly Field
Parish Boundary
CROYDON PARISH
Sewage outfall from Croydon
From Sutton
Reference
Concreted carriers
Underground do
Open carriers
Pipe drains
Manholes on drains
Distributing carriers
Public Footpath

porous soil and subsoil of at least 3 feet in depth, and assuming a sewage flow of 30 gallons per head per day, it would mean that if only the dry weather flow had to be dealt with, and no rain fell upon the farm, it might be possible to continuously treat the clarified sewage of 1,000 persons.

As these conditions are never realised, a margin of area must be provided to take the flow during rainy weather and to allow for the clearing of crops and land being rested, and this reduces the effective quantity per acre to 20,000 gallons for a first-class soil.

On the other hand, on strong clay soils used for surface irrigation purposes, the purification is carried on in the surface soil perhaps not more than 6 inches thick, and in this case 3,000 gallons per acre per day would be the maximum quantity of tank effluent which could be properly dealt with. This at 30 gallons per head represents a population of 100 per acre, and this number should not be increased even if the quantity of sewage per head be materially less than 30 gallons.

Between these two extremes come all the different classes of soil, and an approximate scale of quantities and populations per acre for various qualities of soil can be constructed, but great judgment and long experience are required to determine beforehand in which class to place any particular plot of land, and when applying the scale neither *limit* of quantity nor population should be exceeded.

The following is such a table :—

TABLE 104

	Crude sewage.		Settled sewage		Efficient preliminary treatment Land secondary	
	Gallons.	Population.	Gallons	Population	Gallons	Population
Light sandy loam on gravel and sand .	15,000	375	20,000	500	30,000	1,000
Sandy loam on gravel and sand	12,000	300	17,000	400	30,000	1,000
Peaty soil on gravel and sand	10,000	250	13,500	325	30,000	1,000
Sand and gravel	8,000	200	10,000	250	30,000	1,000
Gravelly loam on gravel and sand	6,000	150	8,000	200	20,000	666
Loam getting more clayey	4,500	125	6,000	150	15,000	500
Heavy loam on marl	3,000	75	5,000	130	12,000	400
Clay soil on clay ...	1,500	50	4 000	120	10,000	333
Stiff clay soil on dense clay	1,000	33	3,000	100	10,000	333

Before attempting to fix the position of a plot of land on the scale, the fullest information must be obtained by sinking trial-holes and bore-holes in different parts. It is found that the constitution of the soil

varies very materially within comparatively short distances, and therefore it is necessary to test at frequent intervals.

Trial-holes are best, as they give better opportunity of noting peculiarities of soil and subsoil than bore-holes, but an auger is useful for intermediate tests between trial-holes, to make certain that the sequence of strata does not vary.

It very rarely happens that all the land required for a sewage farm is of the same value for sewage purposes, and it is therefore necessary to examine closely each plot and determine as nearly as possible what its absorbing capacity may be. Taking then the area of each plot by its capacity, a general average can be struck for the whole area.

The difference between various soils is often one of degree rather than of kind, a light loam gradually merging into a sandy soil in one direction or into a heavy loam in the other, and a heavy loam in its turn merges into a clay.

The size of the individual particles of the soil governs the size of the air spaces between them and so affects the rate of percolation. When, as in the case of clay, the particles become so small that the friction between them and the water is greater than the head on the latter, the process of filtration becomes impossible, and the water simply flows over the surface of the ground, irrigation being the result.

The experts employed by the Royal Commission on Sewage Disposal made very careful mechanical analyses of the soils of the various sewage farms under their observation and determined—

(1) The number of particles in a unit weight of soil.

(2) The size of the air spaces between those particles.

(3) The proportion of humus or modified organic matter which the soil contains.

They expressed the opinion that if a sufficient number of such analyses were available for reference they would afford valuable data as to the volume of sewage of given strength which any particular soil might be reasonably expected to purify.

In a given volume of a coarse gravelly or sandy soil there must be a smaller number of particles than in an equal volume of a light loam, and similarly it is evident that a light loam contains fewer particles than a heavy loam or a clay.

Experience has proved that a light loam gives better results as regards sewage purification than either sand or clay, and the investigation was undertaken with a view of finding an approximate limit of the number of particles permissible in a unit volume of soil which will efficiently purify sewage. Thus an approximate estimate could be made of the quantity of sewage which any soil or subsoil would purify.

An elaborate description is given in Vol. IV. of the supplementary

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TABLE 105.

TABLE OF RESULTS OF MECHANICAL ANALYSES OF SOILS AND SUBSOILS.

NUMBER OF PARTICLES IN ONE GRAMME OF IGNITED SOIL.

	diameter of in centimetres.	Nottingham soil	Nottingham subsoil.	Cambridge soil.	Cambridge subsoil	*Beddington* soil.	*Beddington* subsoil	Aldershot soil.	Aldershot subsoil.	Altrincham soil.	Rugby soil	Leicester soil	South Norwood soil.
	1·0	—	—	—	—	—	—	—	—	—	—	—	—
avel	0·35	3	—	—	4	2	3	—	—	—	—	—	—
	0·25	—	—	2	9	—	—	3	1	3	2	5	1
sand	0·15	4	6	3	9	2	5	1	2	5	2	3	2
	0·075	23	50	30	73	11	21	10	8	49	20	21	13
n sand	0·0375	493	1,118	555	1,088	247	371	191	185	927	274	199	210
	0·015	49,970	85,395	130 870	84,910	86,987	32,075	192,120	179,450	85,884	78,670	83,776	93,556
	0·003	*4,312,000*	*481,800*	*4,334,200*	*540,870*	*3,558,500*	*277,490*	*860,600*	*1,752,200*	*5,312,800*	*3,922,200*	*7,131,000*	*4,307,000*
	0·00075	159,160,000	27,022,000	105,147,000	18,191,000	101,060 000	44,941,000	38,536,000	92,680,000	158,010,000	320,570,000	217,520,000	476,530,000
	0·000255	655,680 000	261,510,000	504 460,000	157,270,000	263,590,000	115,200 000	114,785,000	1,047,500,000	1,120,800,000	2,880,700,000	1,979,600,000	968,060 000
Totals ..		819,101,493	290,000,369	614,122,060	176,087,963	368,295,749	160,510,965	154,373,925	1,142,111,846	1,284,209,668	3,205,271,174	2,201,335,004	1,448,996,682

volumes presented with the Fourth Report of the Commission of the methods employed to analyse the soils, into which it is impossible to enter here, but it may be of interest to give the results so far as they apply to the farms already referred to. See Table 105, p. 612.

It will be noticed that the differences are very marked in the last two columns of "Dust" and "Clay."

The "Dust" referred to consists of particles below 0·001 c.m. diameter which settle from water in twenty-four hours. The "Clay" is the residue in suspension which will precipitate with the aid of dilute nitric acid.

The conclusion arrived at was that the results obtained were too few to draw general deductions, but they show that it is possible to say whether or not a given soil was suitable for sewage purification by filtration, and the same thing holds in a lesser degree as regards suitability of surface irrigation. Further, they tend to indicate that the maximum number of particles per grain of soil which is allowable if the filtration is to be efficient (a suitable subsoil being assumed) is somewhere about 1,000 millions, though this figure is put forward with reserve, as it requires corroboration.

This method of examining soils for suitability for sewage purification appears to be one which is well worth following up, and is essentially one which appeals to the engineer. It is to be hoped therefore that further experiments may in future be made on those lines, and that information on the subject may be accumulated for future reference.

Storm-water Filters.—When laying out a sewage farm it is desirable, especially in the case of an irrigation farm, to construct an artificial filter for use in times of emergency, during long spells of wet weather, and during the reaping of crops.

If the land available is very light sandy soil, the filter may be constructed by banking round a plot and freely under-draining it; the sewage can then be run on until the land is flooded.

In cases where the land is of too retentive a character to do this the filter may be formed by excavating the clay to a depth of 3 to 4 feet and burning it and restoring it to its position as burnt ballast. This can be done at a cost of about 2*s.* per cubic yard, and a rough filter such as described can be constructed for about £1,500 per acre. Engine ashes may be used for the same purpose, or destructor clinkers.

These artificial filters cannot be used for growing crops, and their surfaces should be kept clean and free from weeds. Small quantities of sewage should be applied to them periodically in dry weather to keep them in condition and ready to receive sewage when the emergency arises.

Management of Sewage Farms.—The question of the management of sewage farms has been admirably summed up in an Appendix to the Fourth Report of the Royal Commission on the Purification of Sewage as follows:—

There can be no doubt that even the best of sewage farms, with the most suitable soil, will under continued bad management fail to turn out a satisfactory effluent.

The question of whether or not a particular farm is going to purify the sewage efficiently depends mainly on the manager, assuming, of course, that the farm has been properly laid out in the first instance, that it has a reasonable volume of sewage to treat, and that the manager has (within certain limits) a free hand in the supervision of sewaging operations. The fact, however, must not be lost sight of that he has often a most difficult post to fill, especially with regard to the crops. The effectual purification of sewage, even with suitable land, can only be accomplished when the farming operations are relegated to the background and the production of a good effluent considered of primary importance. On the other hand, the manager knows that the crops will probably form an important item in his receipts at the end of the year, and he not unnaturally wishes it to appear that the farm is being worked economically under his supervision. Hence there is a temptation to grow remunerative crops, *e.g.*, cereals, that cannot be sewaged (at all events for the greater part of the year), or to refrain from the further sewaging of crops which may be damaged thereby; meanwhile the land which is under sewage must needs yield, owing to the lack of rest, increasingly unsatisfactory effluents. There may, of course, be some farms where the large area at command in proportion to the volume of sewage to be "treated" renders the growing of grain crops justifiable, but these are exceptions to the general rule. Land is usually too expensive in the immediate vicinity of towns to allow of this, and the tendency is to take too little rather than too much land for a sewage farm.

Speaking generally, large farms are better managed than small ones, this being in great measure due to the fact that the salary attached to the latter does not always offer sufficient inducement to a competent man to undertake the duties. In many instances there are small districts fairly near together, each with its own sewage farm. In such cases a combined scheme would appear to be advantageous; by adopting this course an adequate salary could be paid so as to secure an efficient manager, while the annual cost of treating the sewage would also be lessened. On the other hand, it is possible to have a sewage farm so large as in a sense to be unwieldy.

It seems desirable that managers should employ day by day some

simple chemical test or tests to enable them to follow the results of the working of the farm to the best advantage. It is probable that attention to this point would do much to foster the desire on their part to turn out the best effluent possible, at the expense, if necessary, of the crops. This question is raised quite apart from the larger one of appointing a qualified chemist in connection with all large sewage disposal works.

In the case of a new farm it would seem advisable, if practicable, that the prospective manager should be on the spot while the works were being carried out, as he would thereby obtain an insight into details which otherwise it might take him some time to discover (*e.g.*, the nature of the soil and subsoil on different parts of the farms, as disclosed by drainage operations). In connection with this, it may be remarked that the soil and subsoil are rarely uniform in nature throughout a farm, and that therefore the various plots cannot all take the same quantity of sewage.

We are unable to recommend the abandonment of farming operations even in connection with filtration sewage farms, because, if intelligently pursued, they make for profit with increased efficiency of the land. The farming operations, however, should always be under the control of the authorities responsible for the proper working of the farm, and the manager should receive written and explicit directions to regard the crops as of secondary importance to the uniform and satisfactory purification of the sewage.

PRECIPITATION.

The method of precipitation *is more properly called* the chemical treatment of sewage; it means the formation of solid compounds by introducing chemical substances into the sewage. The solids so formed, in settling, drag down with them the suspended matters held in solution in the sewage, together with a small proportion of the polluting matters; the proportion, of course, varies with the amount of solid matters deposited. The effluent from the tanks may be discharged direct into the sea or a tidal estuary, and under certain conditions into streams or rivers. In most cases, however, when the final effluent is to be discharged into a small stream, further treatment is required after precipitation either by irrigation or filtration through land, filtration through specially prepared filters, or bacteria beds.

Precipitation tanks are constructed on similar lines to the settlement tanks already described when dealing with Land Treatment, and there are one or two proprietary tanks which will be described later.

The tanks may be worked on the continuous principle or intermittently on the quiescent principle. In the latter case the liquid is decanted

through floating arms such as that illustrated in Fig. 467, made by Messrs Goddard, Massey & Warner. They may be arranged with sluice valves either inside or outside the tanks.

Keirby's Patent Mixer is shown in Fig. 468. It is intended for supplying precipitating material to sewage in lump or powder. It is claimed that this machine will dissolve and distribute with certainty and regularity any of the well-known precipitants (in lump or in powder)

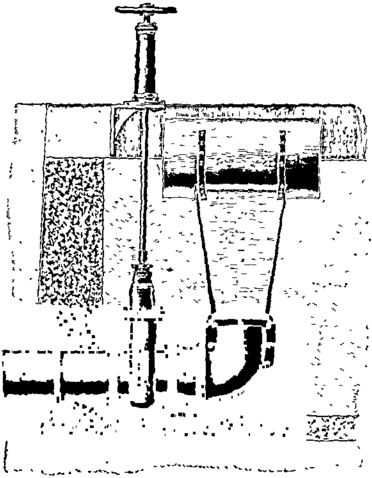

FIG. 467.—Floating Arm, with Sluice Valves.

and automatically vary the strengths of the precipitants in solution according to the increase and decrease in the flow of sewage.

The mixer has a perforated cage or cylinder containing the precipitant, and is surrounded by an outer cylinder sufficiently large for clearance and is mounted upon a shaft in the frame of the outer cylinder; and near the bottom of the outer cylinder is secured a pipe, connected to a water supply, required to dissolve the precipitant, and at another part of the outer cylinder, at about the same level, is an outlet to which

is coupled a swivel joint and pipe, or hollow arm, through which the solution from the cylinder is discharged. This arm is capable of being raised or lowered by a connection to a float in the culvert, drain, sump, or other convenient place into which the sewage is admitted or through which it flows. The inner cage is so arranged that it can be rotated, and by its rotation the water is agitated and produces rapid absorption.

It will be understood that as the flow of sewage increases the float

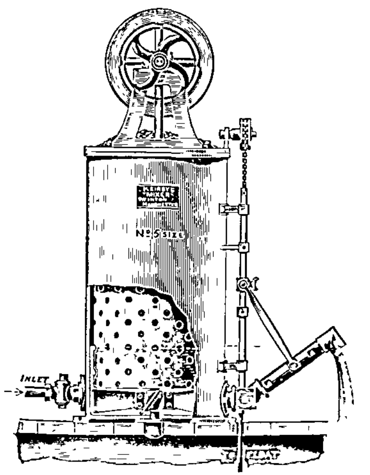

Fig. 468.—Kearby's Patent Sewage Mixer.

will raise the outlet arm, and thereby raise the liquid to a greater height in the cylinders, and so absorb more of the precipitant, and consequently a stronger solution will be discharged, and *vice versa*, as the flow of sewage decreases and the outlet arm falls, the level of the liquid in the cylinders will be lower, and less of the precipitant will be dissolved.

An adjustable slide is secured to the movable arm, which affords a means of regulating the number of grains of the precipitant to each gallon of sewage under treatment.

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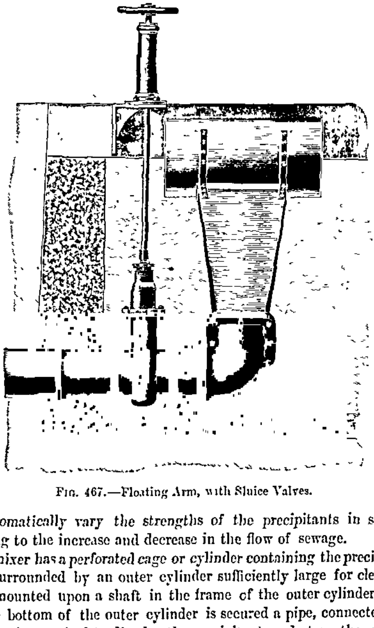

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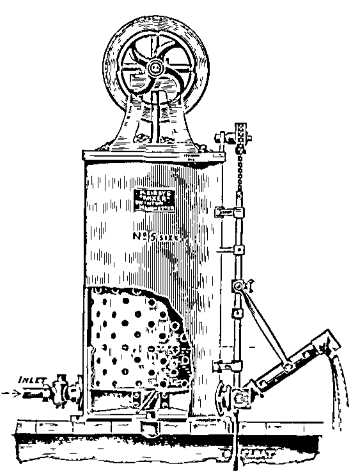

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An adjustable slide is secured to the movable arm, which affords a means of regulating the number of grains of the precipitant to each gallon of sewage under treatment.

Only a very small quantity of water (sewage water or otherwise) is required to be constantly running through the mixer. The quantity does not require varying; it is the strength of the solution that is varied and not the volume.

There is a great variety of these machines, such as that made by Mr. John Wolstenholme, Messrs. Goddard, Massey & Warner, Messrs. Bowes-Scott & Weston, and other makers.

Precipitating Agents.—The conditions for a good precipitating agent are as follows:—

1. It should be cheap and abundant.
2. It should cause *rapid subsidence of the precipitate formed.*
3. It should be neither actively nor cumulatively poisonous.
4. It should not have a tendency to render any portion of the suspended matters soluble.
5. It should not have any distinct colour, nor generate one with the substances it may encounter.
6. It should *ensure the production of a precipitate of minimum bulk* with maximum defecation.
7. The resultant effluent should not be strongly alkaline or acid.
8. The precipitate or sludge should part with moisture readily.

It may be further noted that sewage is more easily precipitated when warm than when cold, and also when the precipitating agent is added *to it hot.*

According to Mr. Dibdin, it is very necessary before adopting any system of precipitation to consider the question of the possible solvent action of the reagent on the suspended matters contained in the particular sewage to be treated. An excessive use of chemicals for precipitating purposes is to be avoided, as it is not only a waste to use *more than is absolutely necessary*, but the beneficial action of the precipitant is actually reduced by such excess.

Variety of Precipitants.—A vast number of precipitants have been tried, of which the following are the principal.

Lime.—The lime process consists in the addition of lime in a perfectly caustic state, in varying proportions, *usually about twelve grains per* gallon, after a preliminary straining of the sewage.

The lime is first of all well slaked with water, and ground in a mortar mill, or lime mixer, so as to be in a finely divided or creamy condition; it is then necessary to thoroughly incorporate it with the sewage, and agitate it well before allowing the mixture to settle. It should afterwards be *allowed to rest quietly for* one hour at least, but where the amount of sewage to be dealt with is large, this is not practicable, and

the continuous system has to be adopted. The precipitate should be consolidated and deprived of its water as soon as possible, as putrefaction soon sets in and creates a nuisance.

The purest lime should be used, such as that obtainable from the upper chalk and the crystalline limestones of Derbyshire and other counties.

The addition to the above of $\frac{1}{4}$ grain of chloride of lime per gallon of sewage is supposed to have beneficial results, especially in hot weather, in preventing the growth of fungus.

The cost of this process has been found to be about eightpence per head of population per annum. This precipitant, however, renders the effluent alkaline, and its discharge into rivers favours decomposition and is very destructive to fish.

Lime and Sulphate of Iron or Green Copperas.—For some years lime in solution and sulphate of iron have been used as precipitating agents in connection with the disposal of the Metropolitan sewage at Barking and Crossness. The proportion employed is about five grains of lime and one of sulphate of iron to a gallon of sewage. The object is to separate the solid matters in suspension from those in solution, the latter being scarcely at all affected by the process, though a certain percentage of them is also removed where the conditions are favourable, but no reliance can be placed on such a result as a rule.

The amount of lime used must be strictly limited, as it has the effect of rendering a portion of the suspended matters soluble, and thus damaging the character of the effluent Special mixers are used for mixing and adding the lime and the iron to the sewage.

The precipitating tanks at Barking and Crossness are on the continuous flow principle, so that the amount of deposits is not so great as it otherwise might be. The composition of the crude sewage as received, according to Mr. Dibdin,* varies very much with the time of year, as all storm-water is included, the average number of grains of suspended matter per gallon being from 29·1 to 38·1, and in the effluent after precipitation from 5·0 to 8·9 ; the matters still remaining in solution in the sewage effluent are those most readily oxidised by the action of the river.

These precipitants were also used by the Manchester Corporation before the introduction of the bacterial system, the proportions being lime from 6·28 to 2·68 grains per gallon, and copperas 6·04 to 2·24 grains per gallon. Huddersfield used lime 3·4 grains and copperas 2·6 grains ; and Oldham lime 4 grains to copperas 1 grain per gallon.

Lime and Alumina are used in the proportions of two of lime to one of alumina, the ordinary quantities being 10 grains of lime and 5 grains

* *Vide* "Purification of Sewage and Water," by W. J. Dibdin, F.I.C., F.C.S.

of alumina per gallon. These quantities may be varied to suit the strength of the sewage.

Spence's "Alumino-ferric."—Lime and alumino-ferric were used as the precipitating agents at Chiswick. The lime (seven grains to the gallon) was slaked and thoroughly mixed with water, and it was then added to the sewage and carefully mixed with it by means of an agitator and a winding channel, along which the sewage and lime flowed, when it arrived at the mixing shed, where the alum in solution, in the proportion of five grains to the gallon, was added and thoroughly incorporated by further agitation. The treated sewage was then led by a distributing channel to the settling tanks. The mode of treatment was adopted on the recommendation of Dr. Tidy, and for a time its employment was satisfactory to the Thames Conservators. In 1907, however, the Conservators pressed the Council to carry out an improved method of purification, and precipitation alone will not meet the requirements of the case.

This mixture has been extensively used as a precipitant in various towns, amongst which may be mentioned Balby, until their new sewage works were built, the proportions in that case being lime 10 grains and alumino-ferric $3\frac{1}{2}$ grains per gallon. Hendon U.D.C. use alumino-ferric alone at the rate of 5 grains per gallon as a preliminary treatment to bacterial filtration. Heywood sewage is precipitated with $8\frac{1}{2}$ grains of alumino-ferric per gallon.

Comparative Advantages of the different Precipitants.—The following are extracts from the report of the State Board of Health of Massachusetts (pp. 786—791), giving the general view of the results of their investigations:—

"The lime process has little to recommend it. Owing to the large amount of lime water required, and the difficulty of accurately adjusting the lime to the sewage, very close supervision would be required to obtain a good result, and even then the result is inferior to that obtained in other ways

"Precipitation by copperas is also somewhat complicated, owing to the necessity of getting the right amount of lime mixed with the sewage before adding the copperas. When this is done a good result is obtained. The amount of iron left in the effluent is much greater than with ferric sulphate, owing to the greater solubility of ferrous hydroxide. Ferric sulphate and alum have the advantage over both lime and copperas, that their addition in concentrated solution can be accurately controlled, and the success of the operation does not depend upon the accurate adjustment of lime or any chemical to the sewage.

"The results with ferric sulphate have been, on the whole, more satisfactory than those with alum. This seems to be due in part to the

greater rapidity with which precipitation takes place, and in part to the greater weight of the precipitate. It is probable, from the greater ease with which ferric sulphate is precipitated, that it would give a good result with a sewage that was not sufficiently alkaline to precipitate alum at once.

"It is quite possible that the same process would not give equally good results upon all kinds of sewage. Special sewages may require special treatment. For this reason, and also on account of changes in the prices of the several chemicals, it is impossible to say that one precipitant is universally better than another.

"In the later experiments, from 25 to 43 per cent. of the soluble organic matter, as shown by the albuminoid ammonia, and loss on ignition, was removed by copperas, ferric sulphate, or alum, costing from 30 to 40 cents per inhabitant annually. In addition to this, all of the suspended matter was removed.

"The average composition of sewage used for these experiments, and also the average analysis of 262 samples of sewage, from November 1st, 1888, to October 31st, 1889, evenly distributed throughout the year, is as follows:—

TABLE 106.

AVERAGE COMPOSITION OF THE SEWAGE USED.
PARTS PER 100,000

	In the Experiments	For the Year
Turbidity ...	65	
Loss on ignition, total	25·4	19·1
In solution, filtered	16·6	12·1
In suspension, difference	8·8	7·0
In suspension	35 per cent	37 per cent
Albuminoid ammonia, total	66	53
In solution, filtered	39	267
In suspension, difference	27	263
In suspension	41 per cent	50 per cent
Free ammonia, total	1·83	1·82
In solution	1·81	1·77

"In the sewage used for the experiments, 41 per cent. of the organic matter, as shown by the albuminoid ammonia, was in suspension, while in the year's sewage the proportion was 50 per cent. Let us take 45 per cent. as the average. If we can remove 30 per cent. of the soluble organic matter, and all of the suspended, we shall leave only 70 per cent. of the 55 per cent. soluble organic matter, or 38 per cent. of the whole; while, if we remove 40 per cent. of the soluble organic matter, the amount left will be only 33 per cent. of the whole.

"Of the other substances present, the insoluble inorganic matters, mainly sand, are removed almost completely, while the soluble salts,

Ferozone, or magnetic ferrous carbon, is prepared from the same mineral that forms the basis of polarite, but is treated in a different manner. It is rich in ferrous iron, and contains also alum, calcium, sulphate of magnesia, and rustless magnetic oxide of iron.

The soluble portion of the material, when mixed with the alkaline sewage, forms a slight precipitate, and the insoluble portion (spongy magnetic oxide) assists in the subsidence, and, from its porous nature, also acts as an absorbent of some of the organic matter; the particles of oxide, being porous and magnetic, part with their polarized oxygen, thereby assisting in the disinfection and deodorizing of the sewage and sludge.

Polarite is the trade name for magnetic spongy carbon; it is prepared from a peculiar description of iron found in certain parts of South Wales. In its original state it is hard, non-absorptive, and non-magnetic. It is carbonized in retorts, and treated by a patented process, and then granulated to the degree of fineness required. This mineral has been tested by Sir H. Roscoe, M.P., F.R.S., etc., and he states that the "porous nature of the oxide, its complete insolubility, and its freedom from rusting, constitute its claim to be considered a valuable filtering material." It contains no poisonous metal, is very hard, porous, and absorptive.

This system of purification has been installed in various places, but is now recognised as being only a precipitation process, and if a good effluent is desired a further treatment on land or bacterial filters is necessary.

The Hermite Process.—This system was in operation in Ipswich. Electricity was employed to produce deodorizing and antiseptic fluid, either from sea-water or from a solution of magnesium and sodium chlorides. The resulting liquid was then applied directly to the drains instead of at the outfall as in other systems. At Ipswich the antiseptic fluid was turned into the head of the main sewer, but another method suggested is to supply it to all houses for the purpose of flushing the w.c.'s and drains. The process depends on the formation of nascent oxygen held in suspension by hypochlorite of magnesia, obtained by passing a current through the sea-water between platinum and zinc electrodes. The oxygen thus obtained is the antiseptic.

In 1905, after working ten years, the Ipswich Corporation decided to abandon the process on the ground that the results obtained did not justify the expenditure. The only other installation on an extensive scale on this system was at Netley Hospital, where all water-closets were supplied with hermite solution.

Electrolysis.—Precipitation by electrolysis, which is also known as "Webster's" process, for the electrical purification of sewage was tried

at Crossness in 1890 and 1891, but was given up on account of the expense of renewing the electrodes.

The following is a description of the method employed by Mr. Webster:—

The first experiments were conducted with platinum plates, but their cost was prohibitive, besides which there was a very slight action on the positive plate pointing to its ultimate destruction; there was no precipitation in the sewage of the matters in suspension, and, as this is absolutely necessary, the more complete this is, the better the ultimate result. It was found that oxidable plates produced the desired results. These plates must be of such material that they have no poisonous after effects, either on land or in rivers. The metals should be either aluminium or iron, but the first-named is out of the question owing to its cost, and then iron, besides having the advantage as regards price, has, in the form of oxide, many valuable qualities, one of the chief being that sulphuretted hydrogen cannot exist when ferrous, or ferric, oxides are present.

The success of the laboratory experiments was such that Mr. Webster asked for and obtained permission to set up plant at Crossness, near the southern outfall of the Metropolitan sewage into the Thames, for the purpose of demonstrating on a practical scale the advantages of the process, and it was conclusively proved that cast-iron plates of the commonest quality employed as electrodes gave the best results. For treating sewage, or impure water, the fluid is allowed to flow through suitably constructed channels containing iron plates set longitudinally, the alternate plates being connected respectively with the positive and negative terminals of a dynamo. The sewage, or impure liquid, in its passage through these channels becomes split up by the electric action. The matters in suspension in sewage, and part of the organic matter, are not only removed by precipitation, but the soluble organic matter is oxidized and burnt up by the nascent oxygen, and chlorine oxides evolved, and this oxidization may be carried to any extent, according to the amount of purification required.

The fact that water is easily decomposed, provided the current of electricity is of sufficient intensity, and also that the effects produced are precisely in accordance with the chemical equivalents of the substances electrolysed, is practically the explanation of the whole system, for the chemical changes that take place in sewage when it is electrolysed depend chiefly on the well-known fact that sodium, magnesium, and other chlorides (which are always present in sewage) are split up into their constituent parts. At the positive pole the chlorine and oxygen given off combine with the iron to form a salt, which Mr. Webster believes is a hypochlorite of the metal, but it immediately changes into

a chloride, which, in its turn, is deprived of chlorine to form ferrous carbonates and oxides. During the chemical action carbonate of iron exists in solution, and its formation is due to the presence of carbonates in the sewage, chiefly carbonate of ammonia. In samples that are absolutely free from dissolved oxygen the ferrous oxide in the white form is precipitated, and, on shaking up with air, it changes to the usual pale green colour. The carbonate of iron at the same time being oxidized, the ultimate precipitate is red, known as ferric oxide (Fe_2O_3), and it is noticed that sometimes this changes, after a time, back again to the ferrous state (FeO), thus showing that it has acted as a carrier of oxygen to the organic matter present.

The organic matter in solution of the particular sewage treated with 0·23 ampères per gallon showed a reduction of 61 per cent.

The bacteria question is one which has probably still to be settled; and being anxious to have some information as to the action of the iron compound produced by electro-chemical decompositions, Mr. Webster had some experiments carried out, with the result that after a given treatment the whole of the bacteria were killed. In the case of experiments carried out in Paris with ordinary treatment by means of iron electrodes, the results were as follows:—

	Raw Sewage		Effluent
Organisms per cubic centimètre ...	5,000,000	...	600

Another experiment, in which the effluent was treated still further, so that a slight odour of oxide of chlorine was perceptible, destroyed all organisms, and the liquid remained sterile.

A thorough investigation of the process was carried out at Webster's experimental works by Sir Henry Roscoe, M.P., F.R.S., and by Mr. Alfred E. Fletcher, F.C.S., F.I.C. (H.M. Inspector under the Rivers Pollution Prevention Act for Scotland), the quantity of London sewage operated upon in each experiment being about 20,000 gallons.

Sir Henry Roscoe reported as follows:—

"The reduction of organic matter in solution is the crucial test of the value of a purifying agent, for unless the organic matter is reduced the effluent will putrefy and rapidly become offensive.

"I have not observed in any of the unfiltered effluents from this process which I have examined any signs of putrefaction, but, on the contrary, a tendency to oxidize. The absence of sulphuretted hydrogen in samples of unfiltered effluent which have been kept for about six weeks in stoppered bottles is also a fact of importance. The settled sewage was not in this condition, as it rapidly underwent putrefaction, even in contact with air, in two or three days.

"The results of this chemical investigation show that the chief advantages of this system of purification are:—

"*First.*—The active agent, hydrated ferrous oxide, is prepared within the sewage itself as a flocculent precipitate. (It is scarcely necessary to add that the inorganic salts in solution are not increased, as in the case where chemicals in solution are added to the sewage.) Not only does it act as a mechanical precipitant, but it possesses the property of combining chemically with some of the soluble organic matter, and carrying it down in an insoluble form.

"*Second.*—Hydrated ferrous oxide is a deodorizer.

"*Third.*—By this process the soluble organic matter is reduced to a condition favourable to the further and complete purification by natural agencies.

"*Fourth.*—The effluent is not liable to secondary putrefaction."

Mr. Alfred E. Fletcher reports as follows :—

"The treatment causes a reduction in the oxidable matter in the sewage, varying from 60 to 80 per cent. The practical result of the process is a very rapid and complete clarification of the sewage, which enables the sludge to separate freely.

"It was noticed that while the raw sewage filters very slowly, so that 500 cubic centimètres required 96 hours to pass through a paper filter, the electrically treated sewage settled well and filtered rapidly.

"Samples of the raw sewage having but little smell when fresh, stank strongly on the third day. The treated samples, however, had no smell originally, and remain sweet, without putrefactive change.

"In producing this result two agencies are at work ; there is the action of electrolysis, and the formation of a hydrated oxide of iron. It is not possible, perhaps, to define the exact action, but as the formation of an iron oxide is part of it, it seemed desirable to ascertain whether the simple addition of a salt of iron, with lime sufficient to neutralize the acid of the salt, would produce results similar to those attained by Webster's process.

"*In order to make these experiments, samples of fresh raw sewage* were taken at Crossness at intervals of one hour during the day. As much as 10 grains of different salts of iron were added per gallon, plus 15·7 grains of lime in some cases, and 125 grains of lime in another, and the treated sewage was allowed to settle twenty-four hours ; the results obtained were not nearly as good as by the electrical method.

"The result of my examination of this process has been to convince me of its efficiency in clarifying sewage, of removing smell, and in preventing putrefaction of the effluent. I am of opinion that such an effluent as I saw at Crossness can be discharged into a river, or, after passing through a thin layer of sand, even into a stream, without causing any nuisance."

The necessary plant consists of electrolytic channels containing the iron plates, the copper conductors and measuring instruments, dynamos, engines, and boilers. Thirty effective horse-power should be provided for treating one million gallons of sewage in twenty-four hours (representing a town of 30 000 inhabitants), assuming that about 450 tons of iron are laid down. This is estimated as ten years' supply, the iron consumed having been ascertained to be about forty-five tons per million gallons per annum. But as the amount of iron laid down is in inverse proportion to the horse-power required, these two factors can be varied to suit the special requirements of each case. It should, however, be borne in mind that the larger the quantity of iron laid down the longer it will last, and the cheaper it will be in the long run.

CHAPTER XVII.

SEWAGE DISPOSAL. ARTIFICIAL BACTERIAL METHODS.

Removal of Suspended Solids.—The elimination of the suspended matter in sewage, in other words, the sludge problem, is still the most pressing difficulty in the minds of sewage engineers.

The methods of effecting this object, apart from the case where the crude sewage is applied to land, are :—

(1) Natural subsidence.
(2) Precipitation by means of chemicals.
(3) Liquefaction in septic tanks.
(4) Separators.
(5) Liquefaction in hydrolitic tanks.
(6) Roughing filters.
(7) Contact beds.

These methods, except the last, have already been briefly referred to, and it is not now proposed to say anything further with regard to the first two, except that where chemicals are used for precipitation the resulting effluent should be neutral, or at least not acid, if the final process involves any form of nitrification, as it is generally held that nitrifying organisms are inhibited by the presence of acids.

In considering this part of the problem in connection with bacterial systems of purification the question may be discussed as to when the solids should be removed, and on this point considerable difference of *opinion exists.*

Many hold that the solids should be eliminated at the earliest possible moment and that the liquid when applied to contact beds or trickling filters should contain practically nothing but matters in solution.

The consideration of this question involves that of the necessity or otherwise of an anaerobic treatment for the correct carrying out of sewage purification ; in other words, is it necessary that putrefaction should take place before oxidation can commence ?

At one time it was looked upon almost as an axiom that this step was a necessary stage in the process of purification ; it may be well therefore to examine the evidence on the other side. Going back to the early

history of the contact bed, we find in the London County Council *experimental beds, and later at Sutton,* the principle adopted of applying crude sewage direct to aerobic filters, and numerous installations have been carried out subsequently on these lines.

It is true that in many of these cases trouble *has* arisen *through* the sludging up of the beds due to the retention of the solid matter, but the purification process was completed in spite of that defect. The slate filter worked as a contact bed, as *suggested by Mr. Dibdin,* is intended to obviate the difficulty of dealing with the solids deposited in the bed, and yet to retain the principle of applying the sewage to the aerobic process without the intervention of an anaerobic step.

The Leeds Corporation in their experiments had a percolating bed constructed for the purpose of testing this point. The bed, which was known as the "Leeds Bed," was constructed of exceptionally large clinkers, the pieces of the medium being so large that no attempt was made to arrest the suspended matter, but on the contrary to allow it to pass freely through the bed.

The sewage applied to this bed was taken direct from the main outfall sewer and was passed through a fine screen with openings $\frac{1}{16}$th inch diameter, and was then taken to the bacteria bed, to which it was applied by means of an ordinary revolving sprinkler.

The effluent from this bed was found to contain a large amount of suspended matter, which was subsequently removed by settlement or by filtration through sand. Both the liquid and the solids were non-putrescible, and the solids were easily dried and dealt with. This bed worked for some years without showing signs of blocking up. The Rothwell Sewage Works subsequently referred to are constructed on the same lines.

It is, perhaps, difficult to determine where the anaerobic organisms in sewage commence *their work, but doubtless they attack* the less stable organic matter such as urea at a very early moment, and their liquefying effect may be going on in the sewers long before the sewage reaches the disposal works. It is therefore impossible to say that no anaerobic organisms are working or are necessary in the process of purification, but it is apparent in circumstances so widely apart as London, Sutton, and Leeds that, whatever may be the effect of the anaerobes before the sewage reaches the purification works, it is possible to carry out a system of purification by aerobic means without a separate anaerobic stage.

One, therefore, is brought to this conclusion, that the separation of the suspended matter may be effected either before or after the oxidizing process, and it will be well therefore to examine the arguments in favour of both courses.

The strongest reason why the solids should be removed before

application to bacteria beds is the danger of choking the beds by the mineral matter and other undissolved solids retained by the beds.

This in the case of ordinary contact beds is a very real danger, but, as already noted, it may be possible to devise means of avoiding it by constructing the roughing or coarse beds of suitable materials from which the retained solids can be removed by flushing or otherwise and be subsequently dealt with.

With trickling beds or continuous filters the danger can be avoided by making the filtering medium of very large size; this can only be done when there is sufficient depth available to give adequate surface in the interstices of the bed for the sewage to trickle over and come in contact with the bacteria; so that with shallow beds this system is not applicable.

Where shallow beds are adopted the medium must be small, and to use small medium involves the application of a liquid free from suspended matter.

As against the choking of the filters there is a very solid advantage to be gained in dealing with the matter in suspension after oxidation, viz., that the sludge is more easily removed either by subsidence or filtration, and when removed it is much more easily dealt with without causing a nuisance than is the case with sludge removed before oxidation.

The difficulties of dealing with precipitated or settled sludge are well known and appreciated by those in charge of sewage works, and it was supposed that the sludge from a septic tank would be even more offensive than either. This view has, however, been considerably modified, and it is now generally recognised that there need be no more nuisance with septic sludge than with precipitated or settled sludge.

In septic sludge the putrefactive changes have largely taken place and been completed before the material is removed from the tanks, whereas this stage has not been reached by sludges produced by natural settlement or chemical precipitation. In practice in most cases it has been found that the sludge from septic tanks has produced very little nuisance on removal, and what smell there is has rapidly passed off.

It is also found that septic sludge is more dense than precipitated sludge, and drains more freely. In Leeds, for instance, the septic sludge contains from 82 per cent. to 85 per cent. of water, against 90 per cent. in sludge produced by other methods. When it is remembered that 80 per cent. sludge contains half the water and occupies half the space of 90 per cent. sludge, it will be seen that this point is of importance.

It should be mentioned in connection with septic sludge that if it is desired to press it into cake it offers considerable difficulty.

On the other hand, the sludge settled out of sewage which has undergone an aerobic process does not putrefy or cause a bad smell, and it is much more easily dried and handled than ordinary sludge. From this point of view, therefore, there is a very strong reason why the solids should not be removed until after oxidation.

Turning now to the quantity of sludge produced, the following table gives the relative quantities of sludge produced by Leeds sewage by the processes named.

The crude sewage contains an average of 42 grains of suspended solids per gallon, and the chemical precipitation was effected by the addition of 10 grains of *lime per gallon.*

TABLE 107.

Grains per Gallon	Sludge.	Effluent.
Chemical precipitation	49	4
Quiescent natural settlement	36	6
Continuous natural settlement	32	10
Septic	16	13

growth and action of anaerobic bacteria, which, put shortly, might be summed up as the absence of light, exclusion of air, and the comparative quiescence of the sewage under treatment.

These conditions can be obtained, as to the first two, either by putting a cover over the tank, or trusting to the scum which rapidly forms on the surface of the liquid, whether it is open or closed.

Quiescence is obtained by giving the tank sufficient capacity and arranging the inlets and the outlets therefrom in such way that its contents are disturbed as little as possible by the flow passing through it.

As to the results obtained from open and closed tanks, they are slightly in favour of the covered tank, which may be seen from the following table of results obtained by the Leeds Corporation from experiments made with open and closed tanks side by side.

TABLE 108.

Grains per Gallon.	Free NH_3.	A I. NH_3	Oxygen absorbed	Solids	
				Soluble.	Suspended.
Effluent from closed septic tank ..	1·59	0·356	4·01	61·7	11·2
Effluent from open septic tank .	1·58	0·377	4·27	62·5	13·6

The average loss of temperature during cold weather in the open tank was 1·6° F., and with the closed tank 0·8° F.

In many situations, for æsthetic reasons, it would be desirable to have septic tanks covered, but, as may be seen from the above, it is not absolutely necessary from the point of view of purification, the difference, generally speaking, being very small indeed.

With open tanks the gases produced are continually being dispersed, and consequently are not so offensive as they would be if bottled up *and then allowed to escape. In large works like Birmingham, where* open tanks have been in use for large volumes of sewage, there has never been any complaint of nuisance from smell.

Mr. Dibdin has suggested the covering of septic tanks with peat moss as an expedient for preventing the escape of noxious gases. For small tanks this can be accomplished by stretching flat galvanized iron wires across the tanks at close intervals, and laying upon them close-woven sheep hurdles, both hurdles and wires having been previously well tarred.

Peat moss can then be teased out, and spread over the hurdles to a depth of 6 inches, and allowed to lap over the side walls. At Carshalton this method was successful in abating a nuisance and preventing further complaints after a period of five years. The advantage of

It is designed for the purpose of dividing sewage or manufactory refuse into three component parts. Not only is the flow free from all solid matters in suspension, but these solids are divided into those having a lesser and those having a greater specific gravity than water.

In many trade wastes the solids so divided form a by-product which would more than pay for their recovery.

The action of the apparatus may be shortly described as follows (see Fig. 469, p. 637) :—

The large cylinder having been first filled with water, the refuse to be treated is turned into the inlet chamber and is thence, by syphonic action, drawn through the large cylinder, the capacity of which is such as to render the flow through it sufficiently slow to admit of the heavier solids sinking to the cone-shaped bottom and the lighter rising to the top.

From the bottom the heavier solids find their way into the deposit chamber, the liquid contents of which are syphoned off at the same rate as the solids enter, so that when full of solids only a comparatively small percentage of moisture remains in this chamber.

The lighter solids are ejected from the top of the cylinder through the smaller cone and pipe provided for the purpose, by turning on the water supply to the cylinder, the other pipes being temporarily closed.

The liquid portion, after being freed from solids in suspension, is drawn by syphonic action into the large covered inverted cone and thence into the effluent chamber and away—the rate of discharge being in exact proportion to that of the flow entering the inlet chamber.

Travis Hydrolytic Tanks.—The hydrolytic tank devised by Dr. Owen Travis, and first introduced at Hampton, is a proprietary tank, and a royalty must be paid for its use. The largest and most recent application of the Hydrolytic Tank is at the Norwich Sewage Works, where the City Engineer, Mr. A. E. Collins, M.Inst.C.E., has adopted this method of separating the solids from the liquid portion of the sewage of that city. The construction of these tanks is indicated in Plate L., p. 640, which shows two, of a battery of four, tanks and chambers designed to deal with a dry weather flow of 3,000,000 gallons per day and to give an effluent containing not more solids in suspension than would be produced by a first-class chemical precipitation process.

The sewage after screening is pumped through a considerable length of rising main which delivers into the well *a*, from which the sewage is distributed by the channel *b* to the downtakes *c*, regulated by penstocks through which it passes into the sedimentation chambers of the detritus tanks *e*. These tanks are similar in construction to the hydrolytic tanks and are designed so that the heavier solids will be

deposited by accelerated gravitation to the sludge valves at the bottom. Each detritus tank has a capacity of 53,500 gallons.

From the detritus tanks the sewage passes by the channel *f* to the distribution channel *h*, and thence through similar downtakes *i*, regulated by penstocks, to the hydrolytic tanks. These tanks are divided into three compartments, the two outer ones *kk* being sedimentation chambers, and the middle one *l* is the reduction chamber. At the bottom of the sedimentation chambers are narrow ports *gg* which lead into the reduction chamber and form the only means of communication for liquids between *k* and *l*.

A large portion of the sedimentation chamber *kk* is filled with concrete or wooden slabs suspended from steel joists in a vertical position with their planes parallel to the longitudinal axis of the tanks. By this arrangement the sewage flows between, and in contact with, the slabs which present a large surface to attract suspended solid matter in the sewage and to abstract, from the liquid, substances in colloidal condition. The materials deposited on the slabs slide down their vertical surfaces and pass through the ports *gg* to the reduction chamber *l*.

The chambers *kk* are open at the top, but the reduction chamber *l* is largely covered over, except for the openings in the gangway as shown in the general plan. The floor of chamber *l* has longitudinal and transverse slopes so as to enable the deposited sludge to flow as completely and as quickly as possible to the draw-off valves, which discharge to a system of sludge drains as shown on the longitudinal section A B.

The relative quantities of sewage passing into the compartments *kk* and *l* are regulated by the weirs at *r* at the outlet ends, and as these weirs are at the same level, the amount of liquid passing over each is proportionate to the breadths. The weir of the reduction chamber is one quarter the width of the two weirs of the sedimentation chambers, and therefore the liquid flowing over it is one-fifth of the total quantity passing through the tank. This body of liquid constitutes a downwardly projecting body which carries with it the sludge and depositing solids out of the sedimentation chambers, thereby ensuring a higher degree of clarification in the liquid issuing from those chambers.

The effluent from the sedimentation chambers of the hydrolytic tank is delivered into the channel *m* and is passed by the by-pass *p* to the main effluent channel.

The capacity of each hydrolytic tank is 260,000 gallons.

The liquid from the reduction chamber is taken through two lines of pipes *j* (shown dotted) to the hydrolysing chamber *n* This chamber is constructed with sloping sides and floor and is almost completely filled with concrete or wooden slabs hung from steel joists between which the liquid passes in the same way as in the sedimentation chambers of the

tank is formed with a circular gutter, round which a sludge-removal pipe is arranged to rotate; this pipe has a full bore opening throughout, so that it cannot become choked, and by its means any sludge or deposit is automatically removed and forced by the hydraulic head in the tank to a point within about 2 feet of the top water level, the removal of the sludge being effected without the necessity of emptying the tank. The inner compartment of the tank is so arranged that fermenting sludge rising from the bottom does not pass into it, but rises in the outer compartment, and is thus prevented from escaping with the tank effluent.

Roughing Filters.—Roughing filters have been used for many years as a preliminary means of removing suspended matter, the general arrangement being to filter upwards and to arrange for means of washing with clean water downwards for cleansing purposes.

More recently various workers in sewage purification, notably Mr. J. Corbett, Borough Engineer of Salford, have experimented with roughing filters of a mechanical type, using a large hydrostatic head to force the liquid through the filters.

This method of dealing with the suspended matter appears to offer a possible solution of the difficulty where the conditions are favourable to obtaining the necessary hydrostatic head without pumping.

In connection with the Leeds bed and at the Rothwell Sewage Works the roughing filter has been effectively used as a means of separating the solid matter after oxidation, in both cases the separation of the resulting sludge and its subsequent manipulation causing no difficulty.

Contact Beds.—Contact beds offer another means of removing suspended matter. When the contact bed system was first introduced it was generally believed that all the solid matter was dissolved by the bacteria present in the bed. Careful measurements of the liquid contents of contact beds dealing with many different sewages have shown that there is a gradual diminution of capacity in every case.

This loss of capacity is due to several causes.

(1) The passing of sand, coal-dust, road grit and other mineral matter into the beds. Material of this character, or at all events the heavier part of it, should be separated by detritus tanks prior to the contact bed.

(2) Degradation of the material forming the filtering medium. This indicates the necessity of using only the hardest material for this purpose. Coke, soft clinker, coal, burnt ballast, and other similar materials are liable to reduction in size.

(3) The consolidation of the material of the bed. Unless the material of a bed is uniform in size, the pulsations caused by filling and emptying

the bed tend to move the small particles into the interstices between the larger, and so to consolidate the whole.

(4) *The growth of organisms on the filtering material.* This action produces a mucus or gelatinous film on the surface of the separate particles of the filters, particularly near the surface. This mucus can be considerably reduced in volume by resting the bed.

(5) More organic solids being taken to the bed than it can digest. Cellulose, fibre and certain vegetable matters are very slowly dissolved and tend to block up the bed unless it is worked very slowly.

(6) The presence in the sewage of matters other than sand and road grit which cannot be reduced by bacterial action. Primary beds which have been at work for a very long time are found to contain a large quantity of humus or ash which cannot be further reduced by bacterial action; this humus is similar to the deposit in septic tanks.

(7) The retention in the bed of mineral solids which were originally in solution, but which by the oxidising action of the beds have become converted into solids in suspension.

An examination of these causes of sludging up in contact beds shows that in some instances remedies can be applied; but even when all that is possible has been done there will inevitably be some loss of capacity taking place and it becomes necessary ultimately to remove the solid matter.

At Manchester, where the largest contact bed system in this country has been carried out, it has been recognised that after four years' work the beds must be cleansed, and that this will be a recurring charge, and efforts are being made to reduce the cost to a minimum.

The beds as originally constructed were made of clinkers which were subject to considerable breaking down, with the result that cleansing was probably necessary in the first instance earlier than would have been the case if the material had been of a harder character.

The method adopted is to wash the material and replace it, making up the deficiency caused by small particles being washed out with new material of a harder kind.

The original cost of the clinker was 3*s.* 6*d.* per cubic yard in the beds. The cost of taking out the material, washing it, putting it back in the beds, and making up the beds is 1*s.* 8*d.*, the proportion of added material being about 25 per cent.

The following are the particulars of cost of washing, etc.:—

	d.	
Emptying bed ...	3·52	per cubic yard.
Filling ...	1·28	„ „
Washing...	4·26	„ „
Haulage, repairs, etc.	2·70	„ „

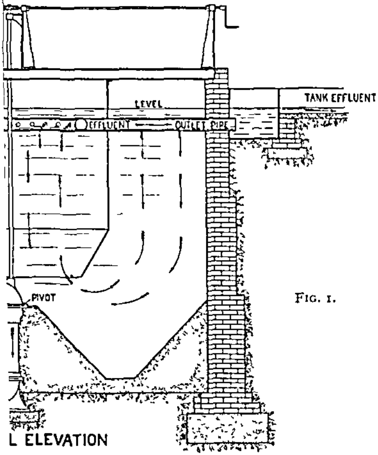
TANK EFFLUENT
LEVEL
EFFLUENT
OUTLET PIPE
PIVOT
L ELEVATION

FIG. 1.

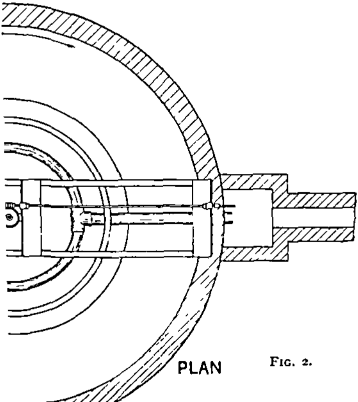
PLAN

FIG. 2.

	d.	
New material...................................	5·78	per cubic yard.
Interest on capital and administration	1·00	„ „
Disposal of slurry	1·46	„ „
	20·00	„ „

The quantity of slurry produced is about 0·42 ton per cubic yard of material washed.

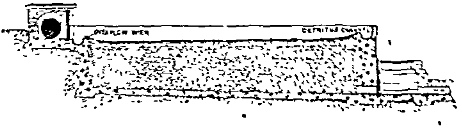

FIG. 470.—Section of Dibdin Filter.

Taking these figures and assuming a holding capacity of 33 per cent., and three fillings per day for four years, each cubic yard of material would have treated about one quarter of a million gallons, so that the cost of removing solids in this manner would work out at 6*s.* 8*d.* per million gallons.

As, however, the capacity of the beds is a gradually reducing quantity, and the number of beds required to deal with three times the dry

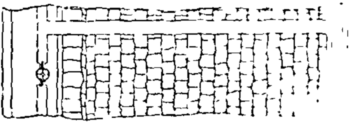

FIG. 471.—Plan of Dibdin Filter.

weather flow makes it impossible to utilise all to their maximum capacity, the cost of cleaning calculated at per million gallons of dry weather flow would be not less than twice the above figure.

The use of slates as the material for contact beds has been recommended by Mr. W. J. Dibdin, who has patented the idea. This system has been tried at Devizes, Trowbridge, High Wycombe, Malden, East Dereham and other places with very satisfactory results. The arrangement of the material in the bed is shown in Figs. 470, 471. The slates

are separated by means of distance pieces, and the experimental tests indicated that the best results were obtained when the distance between the slabs was 4 inches. One great advantage of this system of filling contact beds is the large increase of holding capacity of the beds over any of the media hitherto used. A new bed has a capacity of 85 per cent., instead of the 33 per cent. usually adopted for other materials, that being the figure on which the Local Government Board calculates the sizes of beds.

The Devizes beds, after working for fourteen months with an average of two fillings per day, were found to have a capacity of 50 per cent. of the gross cubic capacity, and by flushing, this figure was increased to 64 per cent. Some of the slates were then removed, and by further flushing the capacity was restored to 82 per cent. of the total cubic capacity.

On referring to Fig. 170, p. 643, it will be seen that the top layer of slates is laid overlapping in such a manner that it forms an automatic screen by the junction of the edges which will be sufficiently separated to allow the finer divided matters to pass between them and the underlying layers, the fibrous and coarser matters being retained on the surface of the slates from which they may be removed from time to time. This enables the particles to thoroughly drain before their removal.

The wide channel receiving the sewage will act as a grit chamber. The sewage will flow over the weir-lip of this channel on to the slates and thereby become aerated. Another point is that as the sewage gradually fills the bed, films of air will be retained on the under surface of the plates. If this layer is only one-fiftieth of an inch deep, and the intervals between the plates 1 inch, the quantity of oxygen so retained will be sufficient to thoroughly aerate the sewage. For instance: Each gallon of water will dissolve about 2 cubic inches of oxygen, which will be contained in 10 cubic inches of air. Two cubic feet of bed-capacity of 50 per cent. will contain 6¼ gallons, which will accordingly have to be supplied with 62½ cubic inches of air.

The plates in 2 cubic feet of such a bed will present a total underneath area of 144 × 24 = 3456 inches super. If the film of air retained under this surface be of an average depth of one-fiftieth of an inch, the total volume of air so retained will be equal to 69 cubic inches.

A sewage containing an average of 40 grains of dried suspended matter per gallon will contain 0·14 grain per cubic inch. If the slate layers are 2 inches apart this equals 0·28 grain per square inch of surface, without allowing anything for the matters which may adhere to the under surface of the slates, or sides of the blocks. If this quantity contains 90 per cent. of water, the usual amount in settled sludge, the

weight will be 2·8 grains of wet deposit, the relative volume being, on the basis of 1 cubic yard to $\frac{3}{4}$ of a ton (= 252 grains of wet mud per cubic inch), 0·011 cubic inch. Thus the average depth of the wet mud on each slate layer will be only about one-hundredth of an inch at each filling. Supposing, for the sake of illustration, that no diminution of this deposit took place either by biological action, oxidation, draining, etc., it is evident that it would require one hundred fillings to obtain a deposit equal to 1 inch per slate surface. At one filling daily this would happen in, roughly, three months, so that in a little over six months under such a supposition the whole of the beds would be full, and unable to take any further quantity of sewage.

That such is not the case is evident from the results obtained at the several installations mentioned.

The daily increment forms but a steady fixed supply, which on digestion leaves a residue from which the major portion of the original albuminous and similar matters have been removed, whilst the original 90 per cent. of water is also largely reduced, and thus the bulk of the remainder is but a fragmental quantity of the original series of wet deposits.

The advantages claimed for slate filling are :—

(1) That the material does not settle together.

(2) The growth of organisms will take place on both surfaces of the slates and will not choke up the water spaces.

(3) The drainage cannot be impaired.

(4) The coarser fibrous material can be kept out of the bed.

(5) The material will not break down.

(6) The solid matter deposited in the bed can be easily removed by flushing.

(7) The working capacity per cubic yard of filter is in excess of any other medium.

The cost of this class of filling depends upon the distance of the works from a suitable slate quarry. An average figure for large quantities of slates in the Midland Counties would be about 25*s*. per ton, to which must be added cost of cartage from station to beds, say 2*s*., and of laying 6*s*. per ton, making a total cost of 33*s*. per ton. As a ton of slates will fill 3 cubic yards of beds, the cost of the filling would work out at 11*s*. per cubic yard. Since the holding capacity of a bed so filled is double that of a bed filled with coke or clinker, the price compares with the latter materials at 5*s*. 6*d*. per cubic yard, but there would be a large saving in the cost of the empty beds.

Relative Merits of Preliminary Processes.—As to the relative merits of chemically treated, settled or septic tank sewage for further treatment

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Relative Merits of Preliminary Processes.—As to the relative merits of chemically treated, settled or septic tank sewage for further treatment

on percolation or contact beds, there appears to be no material difference so far as the final result is concerned, provided the aerating beds are sufficient in size and properly designed.

Apparently all three forms of effluent are easily oxidised by passing them through percolating filters, and an equal area of such beds is required in each case, but the variation in the quantity of suspended solids must be provided for by arranging the size of medium in the filter, its depth, and the abstraction of solids after filtration to suit the quality of tank effluent.

In round figures it may be said that by chemical precipitation the suspended solids can be reduced to 1 or 2 grains per gallon, and should never exceed 5 grains per gallon. With sewage subjected to natural settlement the solids may vary from 5 to 10 grains per gallon, and on the other hand a septic tank effluent may contain as much as 20 grains per gallon. If the percolating filter medium is of fine grade, sludging up is certain to take place with an effluent containing as much as 20 grains of suspended solids per gallon, and if the medium is coarse enough to allow the solids to pass through they must be separated by a subsequent process before discharging into a stream.

On the other hand, when considering the subsequent treatment of these three classes of effluent on contact beds, the quantity of solids in suspension is a most important factor, as experience shows that a large proportion of the suspended solids is retained in contact beds, and gradual sludging up of this class of beds is the universal experience; it is only a question of time how soon the beds must be washed out, and therefore it is obvious that other things being equal it is better to use the tank effluent containing the least suspended solids.

As a set-off against this advantage the cost of chemicals must be considered and the increased bulk of sludge to be dealt with, the difference in cost of disposal, the difference in cost of tankage and capital cost generally. If the life of a contact bed be taken as three to five years, and the cost of washing and replacing the material be taken at from 1*s.* 6*d.* to 2*s.* per cubic yard, a comparison of the total annual cost can be made.

The features of the three methods of preliminary treatment are briefly summarised in Table 110 on p. 647.

Although there has been a general tendency since the introduction of bacterial processes to discard and discredit all chemical processes, it is certainly not clear that under certain conditions and particularly when dealing with sewage containing manufacturers' refuse, it is not both more efficient and more economical to use chemical precipitation in the preliminary process, even if the tank effluent is to be subsequently treated on percolating filters.

OXIDISING BEDS.

Oxidising bacteria beds, or beds in which the aerobic organisms are capable of working are divided into two classes—viz.: Contact Beds and Continuous or Streaming Filters.

Contact Beds.—The contact bed was first used in conjunction with the septic tank at Exeter and for crude sewage at Sutton, and has since been largely adopted, notably at Manchester and Sheffield. The essential feature of this class of bed is that the tank or bed shall be

TABLE 110.—COMPARATIVE ADVANTAGE OF DIFFERENT METHODS OF PRELIMINARY TREATMENT

Chemical Precipitation.	Natural Settlement.	Septic Settlement.
Small tank area.	Small tank area.	Large tank area.
Maximum s[illegible]	[illegible]	Minimum sludge
Sludge easy [illegible] and need [illegible] if any, lime.	[illegible]	Sludge very difficult to press, necessitating the addition of large quantities of lime.
Little danger of nuis-	Little danger of nuisance.	Grave danger of nuisance.

There is no patent covering this method of working, but many patents have been obtained for automatic valve gears to regulate the cycle of operations.

The tank forming the shell of the contact bed may be of very simple construction but must be watertight; it consists of a floor and walls slightly higher than the filtering material which varies in depth from 3 feet to 5 feet. The floor of the bed should have a slight fall for drainage and on it should be laid ordinary land drain tiles at fairly close intervals and concentrating on the outlet valve.

In some cases where contact beds have been constructed on clay land they have consisted merely of excavations in the clay, and this course is advocated by some authorities. It should, however, be pointed out that the Local Government Board will not lend money on works of this class, and they are not recommended as suitable for municipal works, which should be substantial and permanent.

The materials used for filling the beds may consist of coke, coal, clinker, ashes, gravel, granite, burnt ballast, slag, broken saggers, broken bricks, etc., and more recently the slate filter filling introduced by Mr. Dibdin (for particulars of which see page 643).

It was at one time thought that the character of the material was important and that a porous and rough medium was essential. This view has now been considerably modified and it is found that almost any substance is suitable from a purification point of view, but experience has shown that hardness and durability are of the greatest importance.

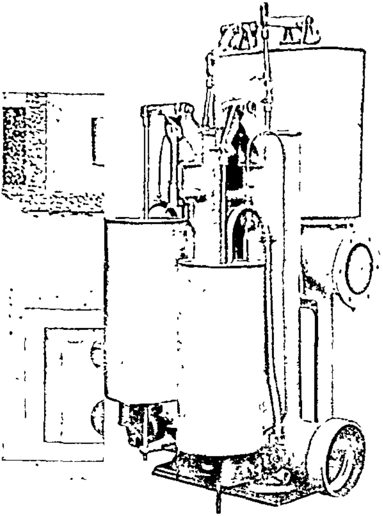
Where double contact is adopted—that is, when there are two sets of beds in series and the liquid is passed through both in rotation—the size of the material in the first bed is made larger than in the second; usually 2-inch to 3-inch gauge for the first contact and 1½-inch to 2-inch gauge for the second. In the Manchester beds these sizes are adopted, but the coarse bed has a thin covering of very fine material a few inches thick on the top to retain as much floating matter as possible.

It is not necessary to provide a very elaborate system of distribution for the sewage on the surface of the material; open troughs laid practically level and so arranged that the liquid will spill over the edges without washing away the material are all that are necessary.

The valves for filling and emptying can be worked by hand if men are constantly in attendance for the purpose, or they may be worked automatically by floats or syphons.

Gear for filling and discharging contact beds is manufactured in several patterns by the Septic Tank Company, Limited, who are the owners of the controlled patents of the Cameron apparatus.

The first application of automatic gear to bacteria beds was made at



FIG

—Type of Gear giving Quick Filling, a Fixed Period of Contact, and Control

Exeter, the gear being that known as the swinging bucket type, illustrated in Plate LII., Fig. 1, p. 648, which shows a self-contained form *of the apparatus suitable for any number of filters from two upwards.*

Another form of apparatus made by the Septic Tank Company, Limited, is shown in Plate LII., Fig. 3, p. 648, which is a gear giving quick filling, a fixed period of contact and control of number of fillings per 24 hours.

This apparatus is suitable for a series of filters, and is arranged so that one or more of the filters can be cut out at will.

Another alternating gear, known as the Type S, Plate LII., Fig. 2, p. 648, *gives the same cycle, and the permanent installation at Exeter is* a typical example of this form.

These gears are manufactured in the following stock sizes :—

4-inch	admission	and	3-inch	discharging valves.
6 "	"		4 "	"
9 "	"		6 "	"
12 "	"		8 "	"
15 "	"		10 "	"
21 "	"		15 "	"

All sizes up to 9-inch admission valves are entirely self-contained. Above 9 inches the sets per filter are built up in two or more portions for convenience in handling.

Plate LIII., p. 650, gives the plan and sections of an installation which shows the principle on which Messrs. Adams' valve gear for operating contact beds is worked

The filling and emptying is effected by means of automatic syphons, which by means of suitable air pipe connections can be timed so that the proper period of contact is obtained. The automatic syphons are so constructed that when once started in operation they work continuously until the refilling of the bed commences, in order that the latter may be entirely drained.

The sewer A enters a diverting chamber in which is the storm overflow B. From the diverting chamber the sewage flows to the two detritus chambers C, the inlets to which are fitted with penstocks, so that either may be closed, and thus shut out of work when desired. From the diverting chambers the sewage enters the scum tanks D. These are constructed with a fall towards the sludge pit G, and thus any deposit can be removed by opening the penstocks shown. The detritus chambers C are cleared in the same way. The sludge is removed from the pit G by means of any ordinary sludge *pump, fixed,* or removeable.

The sewage is shown to enter the scum tanks D through trapped inlets, and leaves it by passing under the Adams' Patent Scum

Plates F, and over weirs into the dosing chamber E. The liquid capacity of the dosing chamber E is equal to that of any of the four contact beds 1, 2, 3, 4, and ensures their rapid filling, thus allowing the greatest length of time for contact, emptying and aeration. Where, however, fall does not allow of the provision of a dosing chamber E (this need only be 6 inches deep), the chamber may be omitted and the supply taken direct from the scum tanks D to the beds by means of the feed pipe. The beds are then filled at the rate the sewage comes to the works. H shows the intake to the supply pipe to the beds (1, 2, 3, 4) in this case laid under their floor. The whole of the apparatus is arranged in a small compass in the centre of the beds. Every part is accessible and close at hand, whilst where desired the whole can be readily covered in by a simple corrugated roof or other structure. The whole of the necessary operations of filling, holding full, emptying, etc., are obtained in automatic rotation simply by the imprisonment and release of air brought about by the sewage itself. Thus there is no wear, with its consequent probability of failure.

Messrs. Jennings manufacture for this purpose an apparatus which is operated by syphonic action, and is shown in Figs. 472 and 473, p. 651.

This apparatus is for distributing sewage from a dosing tank, or tanks, to bacteria beds, so that a succession of these may be utilised one after the other in regular sequence. Deep trap syphons are used, and operated by means of air valves mounted on a frame, as shown (Fig. 472) at 1, 2, 3, connected to the syphons. On the air valve levers a striker is provided, against which the revolving cams 5 impinge. The cams on the shaft are caused to rotate by means of the rise and fall of liquid in the tank. Being positioned one in advance of the other, the cams start the syphons one after the other or in any desired order. Thus any number of filters or sewers will each receive automatically and in turn the entire contents of the tank or tanks.

The chief difficulty in the case of contact beds is the gradual sludging up which takes place, due to the deposit of solid matter in the interstices of the medium. This has a double effect: first, it reduces the water capacity of the bed, and, secondly, by impeding the entrance of air interferes with the aeration of the bed when resting. Unless, therefore, the bed is filled with some medium, such as slate, which can be washed out, it is essential that the solids in suspension should be reduced to the lowest possible limit before the liquid is allowed to enter the contact bed.

When beds are worked by automatic gear three fillings per day can be obtained, but when the valves are regulated by hand two fillings per day is all that can be relied on. The depth of material should not

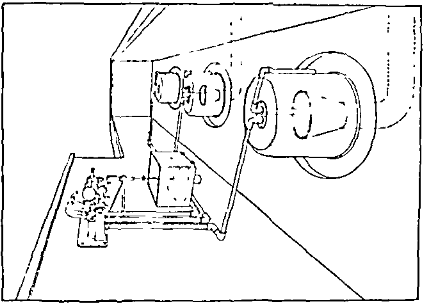


Fig. 473.

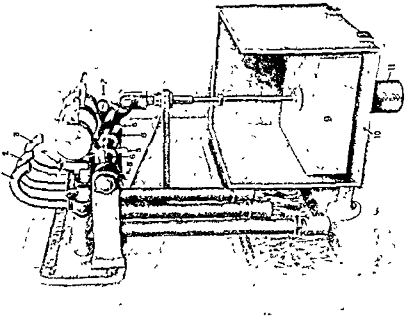


Fig. 472.

Apparatus for distributing Sewage from Dosing Tank to Bacteria Bed.

exceed 4 feet, as with a greater depth thorough aeration becomes impeded, the result of which is that the bacteria in the lower part will be anaerobic, and *the effluent will not be fully oxidised*, and may be putrefactive.

When the beds are used for crude sewage the first contact bed should be calculated at 25 per cent. only of its gross capacity as water space, and the second contact bed at 33 per cent. If the sewage is first clarified the first contact bed may be calculated *at 33 per cent.* Thus with three fillings per day a bed will deal with its gross cubic capacity of sewage daily.

Continuous Filters.—The continuous or trickling filter differs entirely from the contact bed in its action in that it is not enclosed in water-*tight walls and there is no period of filling, resting and emptying, but* the sewage is applied to it from the top and allowed to trickle through it from top to bottom in the presence of air and the organisms on the surface of the material forming the bed.

This form of oxidising bed is now well known and generally recognised as being the best means of effecting the oxidising part of the sewage purification process.

The essential parts of a trickling bed are a firm and more or less impervious floor arranged *with falls to drain to effluent channels*; some form of perforated false floor to carry the filtering medium; retaining walls, which may or may not be perforated, to retain the filtering medium; an aggregation of filtering medium, and finally some device for the even distribution of the sewage over the material.

The most usual form of filter is circular on plan, this form being adopted because the distribution is most frequently effected by means of revolving sprinklers which cover a circular area. This form of bed has the advantage that the retaining walls may be made *lighter in* construction than similar walls which are straight on plan.

The circular form of wall, instead of being purely a retaining wall which can only be in a stable condition by the effect of gravity, introduces the element of tension longitudinally in the brickwork or concrete *and this can be augmented by iron circumferential tie bars in the* body of the wall.

Floors.—The floor of the bed is usually constructed of concrete, and if the foundation be good need only be of sufficient thickness to form an impervious stratum over which the drainings from the bed can flow.

[illegible] and

[illegible] the

unequal stresses, and if necessary must be reinforced to enable it to

distribute the weight of the walls and filtering medium without settlement.

It is usual, in the case of circular beds to arrange the fall of the floor from the centre outwards and construct the effluent channel *outside the* circular retaining wall.

This system, however, is not essential and there are considerable advantages in carrying the channel diagonally across the centre of the

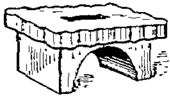


FIG 474.—"Ames" Tile.

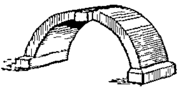


FIG 475 —"Mansfield" Tile

FIG. 476.—"Candy-Whittaker" Floor Tile.

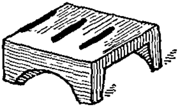


FIG. 477.—The "Stiff" Tile.

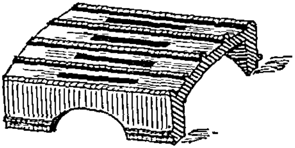


FIG 478.—"Parkes" Tile.

bed and making the floor fall from the circumference towards the diagonal channel.

False Floors.—The false floor is an important part of the bed, although there are numerous examples of beds constructed by merely putting the bottom layer of medium of an extra large size with a few drain pipes placed at considerable intervals.

The aeration of the bottom part of the bed and effective drainage are essential if it be desired to have a fully oxidised effluent and to enable the bed to excrete the solid matter which passes into it.

Where the bed is of other form than circular on plan the falls of the floor are usually arranged on a ridge and furrow system, the furrows discharging into channels laid to a main pick-up carrier.

The earliest form of aerating floor consisted of half pipes 12 inches to 18 inches diameter perforated with holes 1 inch diameter. These half-pipes were made of ordinary stoneware or fireclay and glazed similarly to ordinary drainpipes. It was soon found, however, that this form of false floor with deep beds was not sufficiently strong to carry the superincumbent weight.

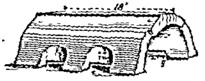


FIG. 479.—"Naylor" Tile.

Numerous forms of floor tile have been introduced for the purpose of overcoming this difficulty and the following are the survival of the fittest.

Ames Patent Tiles.—This form of tile is shown in Fig. 474, p. 653. It has a strong upper surface with corrugated edges and a central opening allowing for free drainage and ventilation whilst the supports are exceptionally strong and in an arched form.

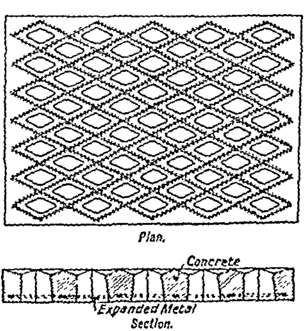


FIG. 480.—Reinforced Concrete Flag for Deep Beds.

Mansfield's Patent Stoneware Aerating Tiles (*Fig. 475*).—This form of tile is approximately like the old form of half-pipe but it has feet which strengthen the construction and prevent the tendency to split down the centre. It is also not weakened by perforations as the original half-pipes were. The drainage and ventilation are provided by the spaces between the tiles which are maintained by a web which is cast on the tiles preventing them from butting up close. The tiles are in short lengths and are easily laid.

The price of a floor formed of these tiles is exceptionally low, but it would not be suitable for a very deep bed. The tiles are largely used at the Birmingham Sewage Works.

The Candy-Whittaker Floor Tile (Fig. 476, p. 653).—This consists of flat tiles which are put together by pitching one against another and

engaging an interlocking tongue at the ridge as shown in the illustration. The tiles are arranged in rows which butt against each other and so prevent spreading. They are tapered so as to leave air and drainage spaces between them, and this form of floor is very strong owing to its triangular shape and the absence of perforations, which are always a source of weakness. The tiles are made of blue Staffordshire ware and are moderate in price.

The Stiff Tile (Fig. 477, p. 653) is manufactured in blue Staffordshire ware and is of excellent make and of very simple form. The upper surface is flat and perforated with slots, and the supports consist of four legs with arched webs between. This forms a very strong floor and is moderate in price.

Parkes' Patent Tile (Fig. 478, p. 653) is very similar to the last-named, and is also made in blue Staffordshire ware.

Messrs. Naylor Bros., Denby Dale, are the manufacturers of a floor tile shown in Fig. 479. This is a strong form of tile, and as all openings are in the base of the tile, the process of filtration is extended to the full depth of the filter. The tiles are easily cleaned, and being salt glazed, inorganic and colloidal matter is not likely to collect on them. A continuous shovelling track is obtained by the flat top and projecting end, and single tiles have withstood without breaking a weight of more than 30 cwts., equivalent to over 9 tons to a super-yard.

Reinforced Concrete Flag.—The author designed a concrete flag, fortified with expanded-steel for this purpose (Fig. 480). This consists of flags 3 inches thick, made of concrete with diamond shaped perforations for drainage and ventilation. The fortification being by means of a large mesh expanded-metal, enables the ironwork to be arranged in the centre of the ribs between the perforations. The flags are made in widths of 2 feet 6 inches and lengths of 3 feet, and they are laid on sleeper walls of brickwork, 4½ inches thick, laid honeycombed, and may be two or three courses in height.

This form of floor is somewhat costly, but is exceptionally strong and durable, and is especially suited for deep beds with heavy medium.

External Walls.—The external walls are usually constructed with honeycombed brickwork to permit of easy ventilation of the sides of the beds.

In the early days of bacteria beds the construction often consisted of wooden palings tied together with iron bands, and the late Colonel Ducat introduced into his bed a form of walling consisting of ordinary land tiles which were built in between piers of brickwork.

The honeycombed form of brickwork was the next modification and is now usually adopted.

Whilst it is most desirable to have as free an aeration of beds of this class as possible, it is apparently not essential to have open brickwork sides, and numerous instances can be found of aeration beds of this kind which are successfully working with solid walls, and in some cases where the bed itself is sunk below the level of the ground.

This form of construction, however, is not recommended, and it is distinctly desirable to allow as free a play as possible of air all round the bed.

In some cases no attempt to make retaining walls has been made, the medium being merely tipped and allowed to take its natural angle of repose, whilst again in other cases the external walls have been very roughly formed by selecting the largest portions of the filtering medium and building them into a rough wall with a very considerable slope.

These methods of construction, however, are not economical, as it will usually be found on going into details of the cost that if everything be taken into consideration, the cost of land, additional floor, additional medium and the loss of area of bed usefully employed, etc., would come to more than the cost of the construction of a retaining wall of proper design.

On the other hand it is not necessary or desirable to go to too great a cost in building retaining walls. If, as has already been said, the walls are circular on plan it will be quite safe to build them 9 inches in thickness up to a height of 5 feet; and by introducing circumferential iron bands it is quite possible to build up to any required height without increasing beyond 9 inches in thickness.

Good sound bricks must be used, especially for the outside course, and it is desirable that the walls should be carried up some few inches above the level of the filtering material to form a wind screen to the revolving sprinklers. The coping may be of brick on edge, terra-cotta or stone, whichever can be most economically obtained in the neighbourhood.

If on the other hand beds are not circular on plan, it will be found necessary to construct walls of slightly heavier character, and in that case the larger the beds the greater the economy in the construction.

Filtering Medium.—With regard to filtering medium, the chief desideratum is to obtain a hard material, and for choice it should be non-porous. The materials which have been successfully used have included similar substances to those already enumerated for contact beds; and the same considerations apply largely to the choice in this case as in the case of contact beds, except perhaps that angularity of form is of more importance than straight cleavage.

The materials which have been most successful have been broken granite, broken saggers, broken bricks, gravel and coal.

The grading of the material is a point on which a great difference of opinion exists, and it may be said that there are two separate schools of thought on this subject, one advocating very small material and the other very large.

There is no doubt that excellent results have been obtained by both methods, whilst on the other hand failures have been recorded with material which was too fine but in which the conditions necessary for success were not complied with.

Broadly speaking, it is, as has already been pointed out when dealing with the question of the elimination of the solid matters in suspension, almost entirely a question of how far that part of the process is to be carried before applying the effluent to the beds which regulates the size of the material for the filter.

If practically the whole of the suspended matter be taken out before filtration then the material of the bed may with advantage be small, whereas if it be desired to less effectually remove the suspended solids then the size of the material must be graded so that the solid matter can freely pass through the bed and be excreted with the effluent.

The action of the trickling filter is due to the presence of organisms on the surface of the individual pieces of medium, and the greater the surface over which the liquid has to flow the greater are the opportunities for the bacteria to carry on their functions. As small medium exposes a greater surface than large, per unit of depth, it follows that it will effect *greater purification per unit of depth. This principle, however, must* be limited by the necessity of thorough aeration and obviously if the material be reduced to such a small grade that the interstices do not permit of a free circulation of air, anaerobic conditions will be set up and the bed will no longer be an oxidising one.

In practice, therefore, the inferior limit of the size of the material has been worked out to about ¼ inch, and a material of this size has been successfully tried in many cases, notably at Hanley, illustrations of which works are given at p. 724. This form of bed, however, must be worked with liquid free from suspended solids.

At the opposite end of the comparison we get what is known as the "Leeds bed" as exemplified by the description on p. 729, in which no attempt at all is made to remove the suspended solids, which are all sent on to the bed; and in this case the material is extremely coarse, ranging from 3 inches to 5 inches in diameter.

This is an exceptional case, and the material would be unnecessarily large in cases where the suspended matter has been reduced to a moderate degree. The usual size is 1½ inch to 2 inches in diameter, and it will probably be found that the best results will be obtained by using material either of the very fine grade or not less than 1½ inch to 2 inches.

As the purification depends upon the area of the surface exposed, it would appear that the depth of bed must be regulated to compensate for the variation in size of material.

According to Dr. Reid's experiments, the main part of the purification at the Hanley Works takes place in the top foot of the depth of the bed, and he draws the conclusion that with fine grade material the essential part of the work can be effected in 1 foot of depth.

It is obvious that with material of from 3 inches to 5 inches in diameter, a bed 1 foot in thickness would present such a small surface for the sewage to trickle over that some of it might even find its way through the bed without even touching a particle at all. Hence, with such a large grade material beds may have to be 10 feet to 12 feet in depth in order to provide sufficient surface to secure a proper degree of purification.

This is a most important point when dealing with cases in which the available fall is restricted, as it frequently happens that the addition of a foot or two to the depth of filtering material will make the difference between pumping and non-pumping.

In such a case it would clearly be best to remove as much suspended matter as possible and reduce the depth of the bed.

On the other hand, if pumping be necessary in any case, it may be immaterial whether the lift is a few feet more or less, and in such a case it may be desirable to increase the depth of the bed and take less trouble about the elimination of the solids in suspension.

With material of the grade of $1\frac{1}{2}$ inch to 2 inches, treating ordinary sewage, the depth of bed necessary may be expected to be of from 4 to 6 feet, the solids in suspension having been reduced to from 8 to 15 grains per gallon by one of the means already described.

Dr. George Reid has made out a very strong case in favour of small material, his experience showing that the best results were obtained from fine grade beds composed of broken saggers of $\frac{1}{4}$ inch gauge.

Table 111 gives the main figures of the analyses, extending from July to December, 1905, of the Hanley Filter, which at the end of that time had been in continuous use for a period of three years, dealing with septic effluent at the rate of 200 gallons per super yard per day, and diagram No. 481 represents graphically the figures included in the table.

It should be noted, however, that the Hanley sewage, where these experiments were carried out, is a weak sewage, and that the solids in suspension were reduced by detritus and septic tanks from 66·5 parts per 100,000 to 7·6, of which half was organic and half was mineral. The suspended matter passing on to the filters was all retained in the top layer of the filter, and it was found that after three years' working the

TABLE 111.

ANALYSES OF HANLEY SEWAGE

PARTS PER 100,000

Sample	No of records	Total solids	Solids in suspension	Solids in suspension (organic)	Solids in suspension (mineral)	Chlorine	Free ammonia	Albuminoid ammonia	Oxygen absorbed in 4 hours at 80° F	Oxygen absorbed in 3 min before incubation	Oxygen absorbed in 3 min after incubation (4 days)	Nitric nitrogen on day of collection	Nitric nitrogen after day of collection	Nitrous nitrogen on day of collection	Nitrous nitrogen day after collection	Column necessary to obscure test lines (inches)
Sewage	18	170 9	63 5	28 5	34 9	11 0	2 151	0 972	5 019	1·862	2 176	0 02	0·10	0 029	0 029	0 5
Detritus tank	13	118 1	17 0	6 8	10 1	10 0	1·643	0 186	2 726	0 975	1 095	0 02	0 09	0 014	0 022	1 6
Septic tank	16	107 8	7 6	3 8	3 8	9 9	1 716	0 110	2 184	0 836	1 571	Nil	0 09	Nil	Nil	1 5
Filter, 1 ft	16	101 5	0 25	0 16	0 08	9 4	0 036	0 052	0 328	0 093	0 067	1 64	2 07	0 003	0 103	Over 24
" 2 "	16	101 1	0 09	0 05	0 03	9 5	0 020	0 037	0 286	0·077	0 060	1 82	1 99	0 011	0 007	"
" 3 "	16	101 8	0 14	0 06	0 08	9 4	0 009	0 031	0 244	0 060	0 052	1 75	1 85	0·005	0·008	"
" 4 5 ft	16	103 5	—	—	—	9 5	0 013	0 027	0 259	0 070	0 039	1 70	1 99	0 005	0 002	"

suspended matter had penetrated to a depth of a few inches only into the bed.

Dr. Reid states that in his experience clogging of filters from suspended matters is more likely to occur with large than with fine grade medium, owing to the fact that the suspended solids in the former case are not retained in the surface layers where it would seem the active aerobic liquefying changes are effected, but are washed into the deep layers, where in place of being liquefied they accumulate and ultimately fill up the interstices. He agrees with the view expressed above that if large medium is to be used it should be of such a size as will allow the suspended solids being washed through. In other words, if clogging is

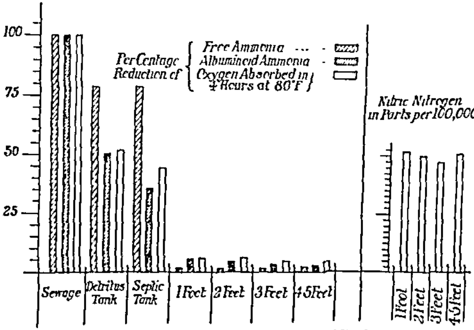


FIG. 481.—Graphic Diagram showing Analyses of Hanley Sewage.

to be avoided the filtering medium must be either very fine or very coarse. The solids must be either retained and liquefied on the surface or washed through and mechanically removed afterwards.

With regard to the degree of aeration found in a fine grade bed, Dr. Reid points to the high nitrification attained by means of fine medium filters, and he is of opinion that if it were desirable to use finer material than ⅛ inch in diameter, there is no reason from an aeration point of view why it should not be done. He considers that the only argument which weighs against the efficiency of a smaller grade medium than ⅛ inch is that with very fine material the suspended solids are apt to be retained on the actual surface where rapid liquefaction cannot take place unless frequent rakings and forkings are resorted to.

On the other hand, the suspendid solids are in a sufficiently fine state

of division to permit of penetration into ½ inch medium, and being thus brought into intimate contact with the highly active aerobic organisms, resolution is rapidly effected.

In Dr. Reid's view the three essential factors in the final stages are time, air, and organisms, and given a sufficiency of air the greater the number of organisms present the larger the amount of work done; provided the organic matter, both in solution and suspension, is brought into intimate contact with the organisms. The factor which governs the bacterial population is the area available for growth, and this may be increased by two methods: either by enlarging the cubic capacity of the filter or by sub-dividing the filtering medium. The sub-division may be carried as far as is possible without preventing the superficial penetration of the suspended solids into the body of the filter, and he points to the Hanley results as an indication that at all events with ¼-inch material there is an adequate air space.

Whilst not going the length of suggesting that all fine grade filters could be reduced to a depth of 1 foot because of the allowance for effluent drains and the large material which must inevitably cover them, he does suggest the practicability of reducing the total depth to, say, 2 feet 6 inches.

It will be seen that the views here expressed are quite reconcilable with those put forward by the advocates of large material, and it is quite possible that ultimately the best arrangement will be found to combine the two views, and that the material forming the body of the bed might be of large grade, but that the surface layer of, say, 1 foot in thickness, where it could easily be got at to be forked or raked over, might be of a smaller grade down to ¼ inch.

Distribution.—Turning now to the question of distribution of the liquid over the surface of the bed, the first and most important point to be considered is the evenness of distribution, and it may at once be said that many of the devices used for this purpose do not by any means give even an approximately equal rate of distribution all over the area. Engineers would do well to make a very stringent requirement in their specifications on this point, and to carry out tests after the installation is at work to ascertain whether their stipulations have been carried out.

The next point for consideration is the capacity of the apparatus to vary the rate of flow from time to time in order to provide for the fluctuations in the delivery of sewage at different hours of the day and those due to the presence of rainwater, which increases the bulk of liquid to be distributed up to two or three times the average.

The third point is the capability of being adapted to intermittent working, as many authorities hold the view that intermittent working

is essential to successful results. This consideration may not weigh so heavily with others who think that intermittent working need not be so rigidly enforced and who are content to rest their beds by sub-dividing the units, so that the beds can be put out of action in rotation during the hours of small flow.

A further point of importance is the amount of fall required for efficient distribution, and this varies from 1 foot to 6 feet in different types. Cases often arise where distributors requiring the larger figure mentioned would be inapplicable on account of the small fall available.

Reliability of working, absence of choking, ease of adjustment, and economy of first cost and maintenance, are obvious requirements and therefore need no comment.

Distributors may be divided into classes as follows :—

(1) Fixed distribution with channels.
(2) Pipe distribution with jets.
(3) Automatic tipping arrangements.
(4) Automatic revolving distributors.
(5) Power-driven revolving distributors.
(6) Automatic travelling distributors for rectangular beds.
(7) Power-driven ditto ditto.

Fixed Channels.

In the first class may be placed, for small beds, ordinary wooden troughs with perforations in sides and bottom or notches cut in the edges over which the sewage can flow. This method gives only very approximate evenness of distribution and is only applicable on a small scale.

Iron troughs can be used instead of wood in the same way, and a stoneware distributor has been brought out by Messrs. Wragge, of Swadlincote, which is less expensive than iron.

One of the chief difficulties with these distributors is to keep the perforations free as they become blocked by the floating matter in the sewage.

Septic Tank Co.'s Distributor.—To avoid this clogging of the trough perforations the distributor illustrated in Fig. 482 has been introduced by the Septic Tank Co., Ltd. In this case the liquid is syphoned out of the trough by capillary action with wire syphons. Distribution by this means gives even delivery with varying rates of flow, and there are no orifices to choke.

The main feature of this distributor consists of an ordinary trough, either of cast iron or artificial stone, the edges of which are trued up, fixed level and fitted every three or four inches of its length with wires passing over the edge of the trough and closely attached thereto.

The action is as follows:—

Directly the trough is filled with effluent and commences to overflow, the main portion of discharge is attracted to and carried down the wires, thus evenly distributing the effluent as to the length of the trough. The troughs are placed fairly near each other, and are fitted with a regulating device adjustable in the first place, and when adjusted, fixed so that each trough gets an equal share of the effluent.

The flow which an ordinary continuous filter will deal with is not sufficient to keep a continuous stream running from each wire, there being about eight wires to every superficial foot, consequently the delivery on the surface of the filter is drop by drop from each wire. When the supply to the channels falls below the quantity which the

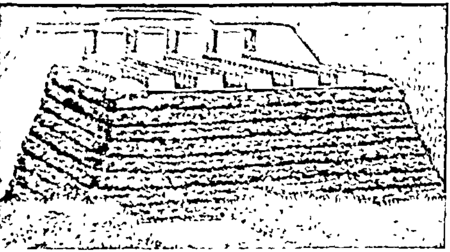


Fig. 482.—Sewage Distributor (Septic Tank Co., Ltd.).

wires are thus delivering, the drop by drop continues until the contents of the channels are pulled down to within a short distance of the end of the wires inside them; the action being both capillary and syphonic. *In most cases the delivery does not cease throughout the day, in spite* of the fluctuations of the flow. Should the drop by drop cease it will recommence again directly the troughs are again filled.

The "Stoddart" Distributor.—*The most advanced distributor in* this class is the "Stoddart" distributor in which the sewage is connected by means of cast iron channels to sheets of galvanized corrugated iron across the ridges of which "V" shaped openings are cut. The liquid escapes through these openings or weirs to the underside of the iron sheet, from which it drips from studs placed at intervals along the valleys of the corrugations, as shown in Fig. 483, p. 664.

In the Fig. A is the corrugated iron sheet distributor with notches in

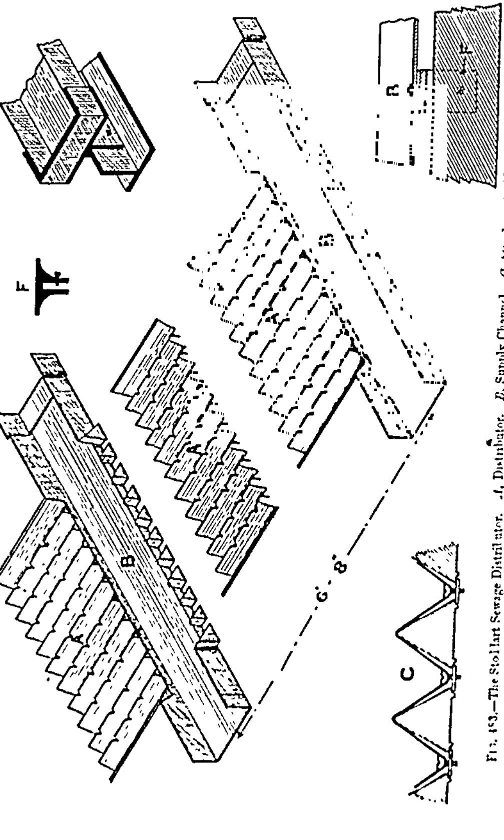


FIG. 483.—The Stoddart Sewage Distributor. A, Distributor. B, Supply Channel. C, Attachment of Distributor to Channel. F, Chair with Set Screw.

ridges and studs in underside of valleys; B, supply channels of cast iron. The attachment of distributor to channel is shown at C; F, chair (*with set screw*) *which is used as a saddle on iron T bars carrying the* channels B. The T bars are carried on piers or walls, and the levels of the sheets A can be adjusted by the set screws in the chair F.

This form of distributor has no moving parts and requires very *little* fall. It is essential to good working that the corrugated plates are kept perfectly level and clean, otherwise the notches do not all discharge equally and the evenness of distribution is destroyed.

The distributor as usually arranged does not cover the whole area of the filter, gangways being left between the corrugated sheets; thus the whole area of the filter is not sprinkled, and this is an objection.

In practice there is a tendency for the corrugated sheets to sag in the middle owing to rough usage when cleansing, and the continuous drip in fixed spots tends to cause a mucus to develop which blankets the top of the bed and requires constant attention by forking and raking over. The cost of the system is rather high and is probably prohibitive for large areas, but on the other hand this distributor automatically adjusts itself to any variations in flow, and if desired can be preceded by an intermitting valve which will give intermittent action.

PIPE DISTRIBUTION WITH JETS.

The class of pipe distributors with fixed jets is one which is in favour where large areas of beds have to be used. For instance, at the Birmingham works many acres of beds are working with this type of distributor and the cost is much less than any other method, working out at about £250 per acre for distribution pipes and jets. The objections to the system are want of evenness of distribution and the large head required. At Birmingham the jets are fixed 12 feet apart and are worked with a 6-foot head and it is found that the jets can be fixed at distances apart equal to double the available head.

The ordinary head for working fixed jets varies from 7 feet to 3 feet; approximately the distribution will extend to a radius equal to the head adopted. The most effectual head for most fixed jets is 5 to 6 feet, and when working with low heads the results, except in the case of the Morley Turbine Jet, are poor.

With most of the jets at present on the market considerable variations will be found in the rate of distribution at different parts of the area sprinkled.

The "Salford" Jet.—*In the* "*Salford*" *Jet (Plate LIV., Fig. 1,* p. 668), the sewage is admitted through six holes, 0·23 inches in diameter, with a slightly spiral direction. The streams issuing from

these orifices unite in a centre cone with a single orifice at the top, out of which the liquid is projected with a revolving motion which breaks up the liquid into a spray.

There is no patent now covering this form of jet.

Harrison and Gjers Patent Jet.—This jet (Plate LIV., Fig. 2, p. 668), which has also been used at Salford, has two holes, each with a diameter of 0·27 inches discharging through an opening into a dished top, and this form of jet covers an oval area.

The Ames Crosta Jet.—This jet (Plate LIV., Fig. 3, p. 668) consists of a cylindrical chamber with a conical top, with an opening $\frac{7}{16}$ths of an inch in diameter. The cylindrical chamber contains a loose spiral with four threads, and the liquid passing up through the spiral gives the water as it issues from the opening at the top a spiral motion which breaks up the jet into a fine spray.

The Adams Jet.—This jet (Plate LIV., Fig. 4, p. 668) is intended to cover a square area and consists of a conical trunk with an opening at the top $\frac{1}{2}$ inch in diameter through which passes a stem $\frac{1}{4}$ inch in diameter, carrying a square baffle plate with sides $1\frac{1}{16}$ inches in length. The underside of this square is curved towards diagonal channels, and by this formation the water issuing from the centre orifice is broken up and spread over an approximately square area.

The Morley Turbine Jet (Plate LIV., Fig. 5, p. 668) combines the principle of a fixed jet with a moving fan with blades on it, which assist in the breaking up of the spray.

From the illustration it will be seen that the water issues through a contracted orifice and impinges upon a curved boss which carries the blades. The action of water upon the latter causes them to revolve, and they in turn break up the water into a very fine spray.

This form of jet is best worked with a head of 4 feet, and with this head will give a practically even distribution up to a radius of 4 feet 6 inches.

The jet is designed to pass 300 gallons per square yard per 24 hours with a head of 4 feet.

Practically no wear takes place upon the moving parts, as the sewage impinging on the underside of the blades carries the weight of the disc, and the only wear is upon the top of the spindle, which can easily be corrected by means of a washer.

The Bryan Jones Sprinkler Jet in use at Birmingham is illustrated in Plate LIV., Fig. 6, p. 668.

The circular orifice A is formed with a conical stem which deflects the upward stream of water. By pressing down the seat B and giving it

a slight turn the jet can be shut off, and by this means the number of jets in work can be varied at different hours of the day and parts of the bed periodically rested. By giving the spindle C a quarter turn a bayonet joint is released and the spindle can be withdrawn leaving

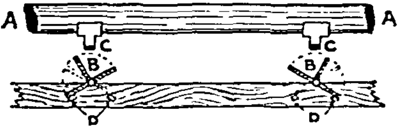


Fig. 484.—Double Trough Tipper Lying on Trestles.

only the seating D; by this means the nozzle can be washed out and cleansed.

Ham, Baker & Co's Spray Jet.—The construction of this jet (Plate LIV., Fig. 7, p. 668) is very simple and the boss carrying the orifice can be taken out of the seating to remove any obstruction. The water in passing through the orifice impinges upon a corrugated plate the height of which can be adjusted as shown by the thumb-screw.

Automatic Tipping Arrangements.

Turning next to the automatic tipping arrangements, there is the

below. This form of distributor gives fairly good results for small beds, but would not be suitable for large areas on account of cost, difficulty of adjustment and trouble from wind.

A tipping arrangement on this principle combined with trough distribution is made by W. E. Farrer, Birmingham, and is illustrated, Fig. 485, p. 667.

The tipping troughs A A discharge alternately into the distribution channels B B in each side of them, and the liquid is distributed through $\frac{1}{4}$-inch perforations spaced 3 inches apart, the channels being fixed 12 inches centre to centre. The tippers are made of galvanized wrought iron and the trunnions are gunmetal bushed; buffers are provided to take up the momentum of the tippers and prevent them from rebounding into the same position. The channels are cast iron and are laid level. They are open at the top, which enables them to be easily cleaned. They are tapered in section and convex at the bottom, and are fitted with inclined planes at the outer extremity to prevent the liquid washing over the ends; the wash of the liquid over the perforations prevents them from clogging. These distributors can be worked with 15 inches of head.

Automatic Revolving Distributors.

The class of automatic revolving distributors is that most usually adopted for streaming filters of moderate size, and a large number of distributors have been made upon this principle, the motive power being derived from the friction between jets of sewage flowing from perforations in the distribution arms with the air, thus driving the distributor after the fashion of a Barker's Mill.

Candy-Whittaker Sprinklers.—The Candy-Whittaker sprinkler (*Plate LV., Fig. 1, p. 672*) is supported and rotates on an upper bearing; the joint at the bottom of the rotating portion between it and the fixed central column is made by means of a trap or seal of mercury, which enables a practically frictionless and water-tight joint to be obtained. A recent important improvement in connection with the patent mercury seal is the employment of a check ring which prevents the possibility of any of the mercury being forced out of the joint by a sudden or unexpected head of liquid. A row of ball bearings is employed in connection with the mercury seal, and the balls being in the mercury are thoroughly protected, the mercury itself acting as a lubricant. It will be seen that the sprinkler is held between two ball bearings placed at the extremities of the central column, thus securing the greatest rigidity possible combined with easy running.

The top ball bearing runs on hardened steel races, which are

removable, so that they can be easily replaced when required. Moreover, the whole of the bearing can be detached without entailing the dismantling of the sprinkler. The screw adjustment enables the bearings to be set with accuracy, and they run in an oil bath containing sufficient oil for six months' use, and they are surrounded by an oil trap which hermetically seals the bearings, so that they are unaffected by moisture or dust.

Another feature of the Candy-Whittaker sprinkler is the patent system of "compensating" arms, which with a sprinkler having four arms enables two of them only to be worked at a time under practically the maximum head, and any flow beyond what the two arms will take passes automatically over a weir-opening into the other two arms. By this system the sprinkler will rotate with the least flow possible, and will at the same time be capable of dealing with a greater maximum volume than would otherwise be possible. Sprinklers on this system are capable of automatically dealing with any flow between 150 and 1,600 gallons per square yard of bed per 24 hours without the employment of an automatic valve or dosing chamber.

For the larger sizes of sprinklers the patent "Buoyant" type (Plate LV., Fig. 3, p. 672) of Candy-Whittaker sprinkler is adopted. In this type the whole of the weight of the sprinkler is supported by a buoy floating in a small well constructed at the centre of the bed; the bearings are thus relieved of all weight, so that the sprinkler will work with less head and periodical renewals of the bearings are avoided. The makers claim this system to be invaluable for large distributors.

The makers of the Candy-Whittaker sprinklers are also the sole makers of the Candy-Caink distributor (Plate LV., Fig. 2, p. 672), in which type only one arm is required, and this is supported on specially constructed wheeled carriages running on one or more circular tracks laid in the bed. The illustration shows one of six 200-feet diameter distributors in operation at Worcester.

Jennings's Distributor.—In this type of distributor, which is of a similar type to the Candy-Whittaker sprinkler, the difficulty of making a watertight movable joint without undue friction is overcome by syphoning the sewage out of a central basin into the revolving arms; the latter therefore have only the friction of the water against the syphon leg to overcome, in addition to that of the ball bearing carrying the weight of the apparatus. In this type of distributor (Plate LV., Fig. 5, p. 672) there are no joints to leak.

One of the difficulties in connection with securing even distribution in revolving distributors is due to the effect of centrifugal force, which, when the speed of the arms increases, throws the liquid towards the outer

extremities of the arms, thus increasing the head upon the perforations furthest from the centre, and causing the liquid to be spread at a greater rate near the periphery of the bed than the calculated discharge.

In order to counteract this centrifugal force Messrs. Jennings have designed an automatic governor, shown on Fig. 486. It comprises a band A around the central column B of the distributor, actuated by a receptacle C with counterbalance F outside the revolving cylinder D through a lever E. The receptacle is filled and emptied by a flexible tube G so that when the distributor is working with the minimum flow the governor is idle, but when the abnormal flow occurs the liquid in the cylinder finds its level in the receptacle, causing same to gradually fall and apply the brake, thus retarding the speed. The amount of friction set up is adjustable for each individual case. When the flow falls back to the minimum the liquid gravitates from the receptacle into the cylinder, and the brake is again idle. It must be understood that the governor does not influence in any way the quantity of liquid passing through the distributor.

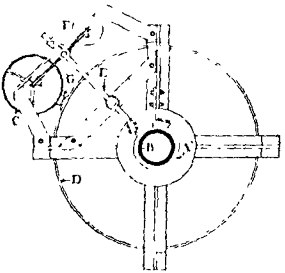


Fig. 486.—Automatic Governor for "Jennings" Distributor.

Mather & Platt's Distributor.—Messrs. Mather & Platt are the makers of a distributor of the same class, but the radiating arms in this case are open troughs with perforations in the sides.

This, it is claimed, enables the arm to be kept clear with greater ease than when pipes are used. The objection to this form of apparatus is that it presents such a large surface to the wind that it does not rotate in windy weather.

The "Ames-Crosta" Distributor (Plate LV., Fig. 7, p. 672) consists of a central column bolted to top of inlet pipe, through which the sewage passes, and thence by means of the ports into the revolving buckets; the sewage then passes into the distributing arms, which are of solid drawn steel.

The whole of the revolving parts are carried by a weatherproof cap, working on ball bearings, the bottom of bucket being guided by a series

of rollers to prevent any oscillatory motion. The rollers being visible, and not submerged in the sewage, is a valuable improvement.

The watertight joint or seal between the fixed and moving parts is formed by means of two gunmetal rings with annular grooves and projections which form a seal to the escape of any liquid. The necessary flexibility of the joint is obtained by means of either a rubber or metal diaphragm.

The ends of the tubes are each fitted with a patent cap which can be removed by a quarter turn to admit of cleaning. A screw is supplied by means of which the whole of the moving parts can be lifted for inspection and removal of the balls, ball path, and seal.

The "Cresset" Distributor.—Messrs. Adams & Co. are the makers of the Patent "Cresset" revolving distributors (Plate LV., Fig. 4, p. 672), in which the joint between the standing and moving parts is made by means of an air lock and there is no mechanical joint. There is therefore no *friction in the joint itself.* The loss of head in this distributor is unusually small. The weight of the distributor is carried by means of a ball bearing running in an oil bath and the general design of the apparatus is good.

The sewage passes through the slots shown in the central column and the discharge is maintained in proportion to the head upon the distributor.

Ham, Baker & Co.'s Distributor.—Messrs. Ham, Baker & Co. are also manufacturers of this type, details of which are shown in Plate LV., Fig. 8, p. 672.

In this distributor there is no mechanical joint or seal to make.

The sewage is conducted to the distributor by means of a horizontal cast iron pipe A, and issues from the central pillar B through fixed pipes C into a trough D, fitted with distributing pipes E. The trough and pipes are connected by means of steel suspension rods F to a head of cast iron G that rests on the top of the pillar B and is provided with ball bearings H, suitably lubricated to allow the distributor to revolve freely on the fixed pillar.

This distributor has been designed with the object of obtaining the full advantage of the initial head of sewage, in order to start the rotary motion; this is commenced by the incoming sewage striking upon blades J (see plan) fixed on the central trough, and is continued by the sewage issuing from the distributing pipes and being sprinkled on to the filter bed. The distributing pipes E have sparge holes spaced to give an equal distribution of sewage over the whole area of the bed. Shortly this may be described as a combination of the principles first introduced in the "Pelton wheel" and the "Barker's mill."

Farrer's Facile Distributor is illustrated in Plate LV., Fig. 6.

In this distributor A is the cast iron feed pipe connecting through the bend B with the cast iron stand pipe C. E is a cast iron cap forming oil reservoir revolving on phosphor-bronze rollers and carrying the tie ropes from the wrought iron distributing arms F. H is an annular iron basin into which the sewage is discharged by the syphons K, and N is an overflow weir. P is a brass gauge tube, forming an automatic cut-off, by which the distributor can be made into a dosing apparatus without having a separate system of valves, the automatic arrangement being so sensitive that it will work with a difference of only 1 inch, so that the sewage can be drawn direct from septic or precipitation tanks without causing a variation in the level of more than a few inches.

The Septic Tank Co., Ltd., also manufacture a revolving sprinkler which is somewhat similar to that of Messrs. Ham, Baker & Co.

The "Fiddian" Distributor.—An entirely different type of sprinkler is that known as the "Fiddian" (Plate LVI., Fig. 1, p. 674) in which the sewage is conducted to the buckets of an elongated water-wheel, which not only revolves on its horizontal axis but travels itself on the surface of the filter by means of wheels fixed on or connected to its axle. The head required to operate this distributor is 15 inches.

In this case there are no joints to trouble with and the sprinkler has no small holes to block up, and it is said to give uniform distribution irrespective of the rate of flow. It has a further advantage of not exposing at any time a large area of sewage to the summer sun or the winter frost.

The small sizes with only single arms are not affected by the wind, and the larger sizes have a larger number of arms which balance one another and so avoid wind action.

POWER-DRIVEN REVOLVING DISTRIBUTORS.

Revolving distributors driven by power are similar in class to the automatic revolving distributors already described, and there is no difficulty in attaching a small electric motor to almost any of the forms mentioned.

The Scott-Moncrieff Distributor is driven by power which may be either an oil engine or an electric motor running on rails on the periphery of the filter and connected to the end of a lattice girder which carries the distribution troughs, and the other end of which is supported on the central column, the whole being rotated by means of the engine or motor (Plate LVI., Fig. 2, p. 674).

On the main trough carried by the girder adjustable slots are provided, supplying the sewage into secondary troughs from which it is discharged over weirs in a thin film. The sizes of the slots can be proportioned to the area of the filter to be covered, and by this means exceptionally even distribution can be attained. The general arrangement, however, is cumbersome, and the weight of the motor and girder is so great that specially strong filter walls, foundations, and rails are required to carry it.

The Adams' Electrically-Driven Distributor shown in Plate LVI., Fig. 4, p. 674, is a simple apparatus and is not unduly costly.

The chief difficulty with mechanically driven distributors is the need for the outer rail and frequently of intermediate rails upon which the driving wheels or carriage of the apparatus travel.

With the distributor under discussion no rails are used. The motive power is obtained from one or more electrically driven fans. A central pin bolted to the summit of the distributor carries the fast and loose contact plates. *The current is automatically cut off when the velocity* of the distributor is sufficient. The driving power is applied where the leverage is the greatest, viz., at the extremity of the arms; thus the assistance of the centrifugal force produced by the sprays is added to the power given by the fan. In the illustration the distributor is shown fitted with two fans and two arms only. The fans are specially constructed for outdoor work and are extremely simple in design.

Travelling Distributors for Rectangular Beds.

The desirability of applying the sprinkler system to a rectangular bed has led to the design of sprinklers for that purpose. Some of these are automatic and some are power driven.

Ham, Baker & Co.'s Travelling Distributor.—In this distributor *(Plate LVI., Fig. 5, p. 674) the motive power is provided by using an* elongated water-wheel very similar to the "Fiddian" distributor, the sewage being syphoned out of a trough as the distributor travels from end to end of the bed. In order that the distribution and intermittency of the liquid may be maintained the apparatus is designed to distribute on half of the bed when travelling in one direction and on the other half when travelling in the opposite direction.

When these distributors are working over adjoining filters the two distributors can be connected by a system of wire ropes and pulleys for the purpose of wind balance, and they are fitted with spring buffers at the ends of the beds to operate the reversing gear.

Jennings' Travelling Distributor.—Messrs. Jennings also manufacture a similar type of travelling distributer, the power being obtained

from a water-wheel operating through wire ropes to the distribution arm which syphons out of the channel as shown in Plate LVI., Fig. 3, opposite. The water-wheel has a fly-wheel on its shaft to ensure uniform motion, and is connected to the distributor by means of straight and cross driving belts.

Willcox Distributor.—Similar travellers driven by electric motors are also in use, one of the most effective of which is that designed by Mr. J. E. Willcox and manufactured by Hartley & Co.

For description and illustrations of this see the description of the Hanley Sewage Works, p. 724.

INTERMITTING GEAR.

All these systems of distribution are more or less capable of being used with intermitting gear, and numerous devices have been designed to effect this object.

The Candy-Whittaker Intermittor is shown (Plate LVII., Fig. 2), p. 676; in it a syphon is thrown in and out of action by floats at different levels, and this apparatus is fixed in a dosing chamber of suitable size and can be made to operate with a very small variation in level.

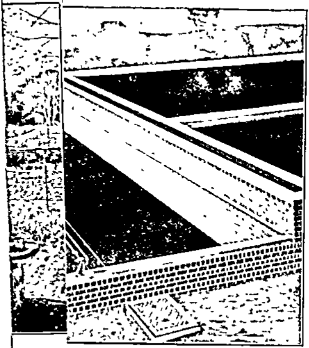
Any number of these syphons can be coupled up to discharge simultaneously or alternately. There are no small discharge pipes liable to become choked and there are no valves to get out of order.

Jennings's Low Draft Forcing Syphons are shown in Plate LVII., Fig. 4, p. 676.

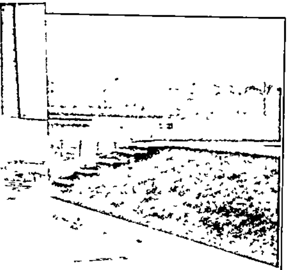
These valves can be set to discharge continuously or intermittently according to the amount of liquid coming down. They will work with a depth of 4 inches of liquid and upwards, and any number can be coupled up to discharge simultaneously or in sequence.

Mather & Platt's Automatic Measuring Valve can be applied under similar conditions. It consists primarily of a flap valve, counter-balance weights and a balance vessel or drum which is filled gradually with liquid, being pivoted about a horizontal axle (Plate LVII., Fig. 5, p. 676).

When the measuring chamber and balance drum are both empty, the counterbalance weights raise the latter and allow the flap-valve to close, the balance drum then being in its highest position. As the measuring chamber fills, a proportion of the sewage is allowed to pass from it through a flexible pipe into the balance drum, which is thus gradually filled; and at a given level its weight will suffice to overcome the counterbalance weights and the pressure of the sewage on the flap-valve, and will open the latter, thus allowing a measured quantity of sewage to be discharged into the troughs or pipes for spreading over the bacteria beds. The balance drum discharges its contents meanwhile,



or. gs" Travelling Distributor.



and thus when the measuring chamber is empty, the flap-valve closes again by the action of the counterweights, and the chamber is ready to receive another quantity of sewage.

Ham, Baker & Co.'s Intermitting Valve (Plate LVII., Fig. 1, p. 676).—When the sewage rises to top water level it overflows the edges of the small trough shown in section against the central wall and passes through the pipe into the balanced bucket in the valve chamber. When the bucket is sufficiently full it is automatically depressed, thus lifting the float shown at low water line and the flap-valve attached to it.

This allows the contents of the measuring chamber to pass through the supply pipe (on which is fixed a controlling and regulating sluice valve) into the distributor, and so on to the bed.

The bucket is self-emptying, and when empty is brought back to its original position by the balance weight fixed on the end of the lever remote from the bucket, to which end is attached, by means of a chain, the float and valve.

The float keeps the flap-valve open till the sewage has fallen to low water level, when it loses its buoyancy and the valve closes.

Adams & Co.'s Low Draft Syphon (Plate LVII., Fig. 3, p. 676). —The illustration shows the Adams' Patent System of dosing automatically in sequence or desired rotation any number of revolving distributors, contact beds, or several filtering areas by means of simple syphons. Almost any number of these may be placed in one dosing tank to discharge to as many outlets as are required. By a system of bye-passes, the syphons may be set to operate in any desired order, and any one or more may be entirely shut out of the cycle if desired.

Coleman's Patent Automatic Sewage Valve (Plate LVII., Fig. 7, p. 676) is a simple and effective automatic apparatus for the intermittent discharge of sewage.

The valve is operated by a float and a mercurially balanced beam. The sewage as it rises in the measuring tank raises the float to the required height, in which position it is retained by an adjusting screw and the balance weight and valve until the float is nearly submerged. As soon as the lifting power of the sewage lifts the float and tilts the lever, the mercury flows from the lower end of the beam and the combined action of the float and mercury open the valve and the sewage is discharged, after which the valve is again closed by the apparatus automatically resuming its normal position. The mercury balance makes the action of the valve certain and automatic.

Hodgson's Intermitting Valve has been designed to enable rotating sprinklers to be supplied direct from a septic or other tank of large

superficial area, thus avoiding the head usually lost in a dosing tank. A dose which would lower the level in a dosing chamber by 1 or 2 feet would only lower the level in a septic tank by about 1 inch, and thus the sprinkler has a practically constant head to operate it whenever the valve allows sewage to pass.

Plate LVII., Fig. 6, shows a plan and elevation of the apparatus placed in a chamber which is in connection with the septic tank.

The apparatus consists essentially of three parts :—

(1) A seating S, through which the liquid discharges.

(2) A valve cap C, attached to arms which rotate about the pin P and nearly balanced by the weights W W.

(3) Two floats, F F, attached to a frame, also rotating about P and carrying two adjusting weights, A A.

The action of the apparatus is as follows :—

When the upper level in the septic or other tank is reached, the buoyancy of the floats is sufficient to overcome the force due to the weights A A, and the frame carrying them commences to rotate. After moving through a small angle it comes into contact with a lug on the cap C and lifts it, allowing the septic tank to discharge to the sprinklers.

The discharge continues until the given lower level is reached, when the floats have too little buoyancy to support the weights A A. The cap and the frame then return to their original positions and the discharge ceases.

Area of Beds.

The quantity of liquid which can be dealt with permanently on percolating beds depends on the strength of the sewage and the degree of preliminary treatment which has taken place. It will be found that in experiments which have been carried out at various towns the rate of flow has varied from 150 gallons per square yard per day to as much as 450 gallons per square yard. In such experiments the rate of flow has been kept more or less constant throughout the 24 hours, and has not fluctuated with the volume of sewage at different hours of the day, or when rain falls.

In dealing with the design of works for the whole flow of sewage of a town these conditions are not maintained and the beds must be capable of accommodating themselves to the fluctuations of hourly flow as shown on the diagram p. 30, and must also be able to take three times the mean dry weather flow.

The regulations of the Local Government Board take into consideration the depth of the filter, and it is generally assumed that a filter is capable of purifying a quantity of sewage proportionate to its depth.

(4) Double contact beds must be provided if an equivalent degree of purification is required to that produced by a continuous filter.

(5) Contact beds must be worked by automatic gear if three fillings per day are required, but may be operated by hand if two fillings are sufficient.

(6) Generally speaking the gear for operating continuous filters is less liable to get out of order than that for contact beds.

(7) Where the facilities for reducing suspended solids are limited, contact beds will sludge up and deteriorate much more quickly than continuous beds.

(8) Percolating beds are more adaptable to fluctuating rates of flow than contact beds.

(9) The first cost of percolating filters is less than that of contact beds for equal quantities of sewage.

(10) Generally speaking continuous filters give better results than contact beds.

Broadly, it may be said, that with crude sewage contact beds are inapplicable except when constructed of slates on the Dibdin principle, on account of the rapid sludging up of the rough bed. With percolation beds constructed of sufficiently large material it is possible to obtain a well-oxidised effluent with crude sewage, but the process must usually be followed by settlement, filtration or land treatment to remove the solids in suspension passed through the beds.

With septic tank effluent or settled sewage excellent results can be obtained with double contact beds at the rate of 90 gallons per cubic yard in each bed with two fillings per day, but the life of the beds will not extend beyond five or six years before they require to be dug over and the material washed. Percolation beds will deal with this class of liquid for much longer periods if constructed of sufficiently large material to evacuate the solids in suspension, which should be subsequently settled out, as is done at Birmingham.

With precipitated sewage, containing not more than three to five grains per gallon of suspended solids, contact beds have a longer life than stated above even with three fillings per day, and percolating filters will produce an effluent quite satisfactory for all ordinary rivers whilst giving greater elasticity than contact beds for increased output in wet weather.

Storm-water.

The ordinary requirements for dealing with storm-water are now fairly well established at six times the dry weather flow of sewage, this quantity being calculated on the mean rate of flow throughout the twenty-four

Of the six volumes, three are usually to be fully treated as if consisting of ordinary sewage, and the other three volumes may be partially treated on a special area of land set apart for the purpose, or on filters working at the rate of 500 gallons per square yard per day with a depth of three feet.

The diluted sewage contains the ordinary domestic sewage and trade effluents (if any), together with the washings of streets, backyards, roofs, gutters, etc., and in most cases a good deal of solid matter which has been deposited in the town sewers, and which is flushed out by the greatly accelerated flow caused by the increased volume in those sewers which at ordinary dry times are not flowing nearly half full.

At the commencement of the storm the sewage is often much worse than the ordinary dry-weather sewage, but the excess of impurity consists almost wholly of suspended matters, and if these can be successfully eliminated, the remaining liquid is generally very dilute. In Leeds, where the sewers are on the combined system, all rainwater being taken into the sewage sewers, the solids in suspension in times of rain are nearly three times as great as in the dry-weather sewage.

This indicates that the works installed for the purpose of dealing with the second three volumes of storm-water should contain large detritus or settling tanks, whereas the usual practice appears to be to separate this portion of the flow before it reaches the ordinary precipitation or septic tanks, and to take it direct to the storm-water filters without settlement of the solid matter.

A good arrangement is to provide a special settlement tank to be reserved for storm-water, and to be worked on the continuous flow system, but placed at such a level that it can be emptied, after the rainfall has ceased, either on to the filters or on to land, so that when a fresh storm commences the tank may be empty and ready to receive the first flush of solid matter brought down before the liquid commences to overflow and be discharged on the filters.

The method of distribution of the liquid on the storm-water filters is in many works unsatisfactory, and it streams through the beds without receiving much purification. If sufficient fall be available fixed jets are useful for spraying the liquid over the beds, or if there be insufficient fall for this the beds should be constructed as contact beds, and the valves should be closed until the bed becomes waterlogged; they can then be opened sufficiently to allow the effluent to be discharged at the same rate as the storm-water is entering. By this means even distribution can be obtained.

The ordinary storm-water filter is open to the objection that in long-continued periods of dry weather the bed becomes so dry that the bacteria are more or less starved out of existence, and when the bed

is suddenly called upon to work to its full capacity it is not in a condition to do so. In order therefore to keep the beds in condition they should be occasionally dosed in dry weather with ordinary tank effluent, but the quantity of the dose must not be more than the bed can efficiently purify.

Hitherto this subject has not received so much attention at the hands of experimenters as the ordinary dry-weather flow of sewage, and the Leeds Corporation experiments are perhaps the most exhaustive which have been carried out.

These experiments were made on the "Leeds Bed," which was a coarse-grained percolating filter treating fresh sewage at the rate of 200 gallons per square yard per 24 hours; whenever storms occurred the dilute sewage was increased up to 600 gallons per square yard, and when the dilution was sufficient up to a rate of 1,200 gallons per square yard per day.

It was found that these rapid rates of flow washed the accumulation of solids out of the bed, and that the effluent contained more solids than the storm-water.

When therefore the crude effluent was taken, including the suspended solids, the purification shown was practically very small; after a subsequent fine filtration for the removal of the solid matter the final purification showed an average of 75·3 per cent. measured by albuminoid ammonia, or 90·9 per cent. measured by oxygen absorbed.

By reason of the flushing out of the solid matter too fast to permit of efficient oxidation, the filtrate during storm times with its suspended matter was invariably putrescent; but after removing these solids by mechanical filtration a non-putrescent result was obtained which was analytically better than the West Riding Rivers Board Provisional Standard, and was sometimes even better than the dry weather results. This was true both of the 600-gallon and the 1,200-gallon rates, but better with the former than the latter.

nitrates by further oxidation. After storm-water treatment the filtrates were deficient in nitrates, and this had a detrimental effect upon their keeping qualities. The bed, however, soon recovered in dry weather, but in cold weather did not return to its normal efficiency at once.

The following tables show the average results obtained in the period August—December, 1903, which was an exceptionally wet year :—

TABLE 112.—600-GALLON RATE (AVERAGE OF ANALYSES).

Grains per gallon	Free NH_3	Alb NH_3	Oxygen Absorbed	Nitrogen as Nitrates	Aeration test, c cs O per litre		Suspended Solids	Soluble solids.
					Saturated	After 24 hrs		
Storm-water	·937	·287	5·29	—	—	—	44·5	48·1
Crude filtrate	·359	·229	2·89	·029	6·0	Nil	28·1	47·7
Purification .	61·7%	20·2%	45·4%	—	—	—	36·8%	·83%
Filtrate (fine filtered) ..	·341	·065	·585	·019	6·0	3·75	—	—
Purification	63·6%	77·3%	88·9%	—	—	—	—	—

TABLE 113.—1,200 GALLON RATE (AVERAGE OF ANALYSES)

Grains per gallon	Free NH_3	Alb NH_3	Oxygen absorbed	Nitrogen as nitrates	Aeration test, c cs O per litre		Suspended solids	Soluble solids
					Saturated	After 24 hrs		
Storm-water ..	1·16	·328	6·31	—	—	—	56·1	43·1
Crude filtrate .	·590	·477	7·04	·010	6·0	Nil	58·0	44·8
Purification	49·1%	Nil	Nil	—	—	—	—	—
Filtrate (fine filtered) ..	·426	·088	·705	·011	6·0	2·75	—	—
Purification .	63·2%	73·1%	88·8%	—	—	—	—	—

A further series of experiments were made with precipitated storm-waters on a percolating filter 6 feet deep filled with 3 inches medium and used in dry weather for precipitated sewage, containing an average of 4·4 grains of solids in suspension per gallon, the quantity being 100 gallons per square yard per day.

During periods of storm, the storm-water was allowed to flow through a tank at a speed equal to a four hours' flow, about 1¾ grains of lime and ½ grain of aluminium sulphate being added to assist the sedimentation of the solids. The clarified storm-water was then distributed over

the filter at the rate of 600 gallons per square yard—*i.e.*, six times the normal flow.

The effluents obtained, although containing more suspended solids than normal, were excellent in character, being well aerated, well nitrated and non-putiescent.

TABLE 114.—AVERAGE OF ALL ANALYSES MADE DURING STORMS FROM JULY, 1904, TO FEBRUARY, 1905.

Grains per gallon	Free NH_3	Alb NH_3	Oxygen absorbed	Nitric N	Incubator test		Solids.	
					Before.	After.	Soluble	Suspended
Storm sewage	1·22	·452	7 62	—	—	—	49 9	61 3
Precipitated storm sewage	1·27	·201	1·48	—	—	—	50 0	6 2
Filtrate	337	·091	717	920	·229	·239	62 3	4 9
Percentage purification	72%	79%	90%	—	—	—	—	92%

Commencing March 1st, 1905, the flow of precipitated sewage on to the filter was increased to 200 gallons per square yard in dry weather and to 1,200 gallons in storm times. This increased rate of flow did not make any appreciable difference to the condition of the effluents.

The following is the average of all storm-water which came down to the works between March 1st and December 31st, 1905 :—

TABLE 115

Grains per gallon.	Free NH_3	Alb. NH_3	Oxygen absorbed	Nitric N	Incubator test		Solids	
					Before	After	Soluble	Suspended
Storm sewage	1 75	0 652	8 01	—	—	—	74 0	44 6
Precipitated storm sewage	1·72	0 342	2 55	—	—	—	69 1	4·7
Filtrate	0 351	0 070	0 538	1·12	0 199	0 205	67 0	2 8
Percentage purification	80%	89%	93%	—	—	—	9%	93%

These results compare favourably with those obtained from a percolating storm-water filter of the usual type used with crude diluted sewage. The filter was 3 feet deep, and was constructed like an ordinary contact bed filled with fine clinker 3/8 inch to 5/8 inch diameter to which was added a top layer of very fine clinker to a depth of 6 inches, as in the Manchester beds, distribution being by means of grips cut in the surface material. During storm times, crude storm-water was discharged on to the filter at the rate of 500 gallons per

square yard per day until the bed was full. The outlet valves were then opened to such an extent that the rate of discharge was equal to the rate of distribution, thus causing the storm-water to stream through the body of the filter as evenly as possible. This procedure continued until the end of the storm. In dry weather the filter was allowed to rest.

The following is the average of all analyses referring to this filter:—

TABLE 116.—JULY, 1904, TO FEBRUARY, 1905.

Grains per gallon.	Free NH_3	Alb NH_3	Oxygen absorbed	Nitric N	Incubator test		Solids.	
					Before	After	Soluble	Suspended
Storm sewage ...	1 22	452	7 62	—	—	—	49 9	61 3
Filtrate ..	418	147	1 70	·343	·272	317	64 1	9 1
Percentage purification	65%	67%	79%	—	—	—	Nil	85%

The results obtained by the increase of the rate of flow upon the percolating filter indicate that it may be better, instead of using the ordinary type of storm-water filter, to provide increased tankage capacity for the purpose of separating the solids in suspension in the storm-water, and to make a liberal provision of percolating beds and so deal with the full six volumes of storm-water on the same set of beds as is used for the ordinary dry weather flow.

STERILISATION OF SEWAGE EFFLUENTS.

Bacteriologists are apparently agreed that pathogenic organisms are present in effluents from land treatment and in at least to an equal degree in the effluents from bacterial processes of sewage purification.

Dr. S. Rideal concluded from his experiments at Caterham that nitrifying filters removed 98·5 per cent. of the coli organisms and all, or nearly all, of the enteritidis.

When therefore the final effluent of a sewage works is discharged into a river from which a public water supply is drawn or watercress is cultivated, or into an estuary in which shell-fish are reared, it becomes a question whether or not means should be taken to sterilise the effluent, and if so at whose expense this process should be carried out. The Royal Commission on Sewage Purification have drawn attention to this point, and have suggested that the cost should be borne partly by the sewage producing authority and partly by the water supply authority.

In the past efforts have been made to produce sterility in sewage, but

they have been applied to the crude sewage and not to the effluent. The precipitation processes of purification in vogue years ago tended to produce sterility by heavy dosing with chemicals, often producing excessive alkalinity or excessive acidity; and other processes such as Webster's *Electrolysis* method, the *Hermite System* and *Reeves Process*, all applied solutions of a bactericidal character to the sewage before it arrived at the sewage disposal works.

Since the recognition of the useful part played by bacteria in the sewage purification process it has been evident that such systems are wrong in principle, except possibly in the cases of sewage discharged into a tidal estuary where there are oyster or other fish layings which might otherwise be contaminated and of storm-waters which might otherwise pollute a drinking-water stream.

The first application of a sterilising process to a final sewage effluent after utilising the bacteria for purification purposes was at Maidenhead. The sewage there was purified by chemical precipitation and subsequent filtration, and to the effluent was added 1 part to from 400 to 600 of effluent, of a liquid called "Electrozone" obtained by electrolysing sea-water or brine containing 2 or 3 per cent. NaCl. Bacterial examination showed that the germicidal action was very marked and that the final effluent contained very few bacteria. The process is not now in use.

At the Guildford Sewage Works a somewhat similar process is installed.

Briefly, it consists of the electrical decomposition of salt and water or sea-water in a specially designed electrolyser having a large superficial area of electrical surface, which permits of the use of a high density of current at a very low voltage, thereby securing economy of operation. The type of electrolyser which would be most suitable for sewage works has an electrical surface of 57·5 square feet in one pole, carrying a current of 2,700 amperes at 5 volts. As the quantity of hypochlorite is dependent upon the amperes only, the economy of this machine is at once apparent. In addition—and this is a most important factor commercially—the capital outlay for such a plant is extremely low. The process is very similar to the "Hermite" treatment, being the application of oxy-chlorides in such quantities as may be required to sterilise sewage effluents. By the Guildford experiments it was found that when an effluent comes up to the recognised standard of purification such as is obtained after land treatment or secondary filtration in bacteria beds, 3¼ gallons of oxy-chlorides per 1,000 gallons of effluent is sufficient to reduce the bacillus coli—a bacillus present in all sewages and allied to the typhoid bacillus—from 100,000 per cubic centimetre before treatment, so that none could be found in a cubic centimetre

after one hour's treatment. The total number of all organisms was reduced from over 900,000 to 450 in less than two hours. In a raw sewage 18½ gallons per 1,000 reduced the coli from over 1,000,000, so that none were found in 1 cubic centimetre, and the enteritidis spores from over 1,000 to less than 10 in 5 hours, and the total number of all organisms from 23,200,000 to 540.

Dr. Rideal, who carried out experiments at these works, states that the germicidal value of the electrolytic solution, containing chlorine-oxides and other compounds, was greater than that of the equivalent of free chlorine liberated chemically. He established an easy practical guide to the amount of re-agent needed. There was a very nearly constant relation between the five minutes' oxygen figure, representing the amount of the agent that would be at once taken up by the organic matter, *and the quantity of the oxy-chloride that* was needed, so that there would be an excess capable of killing the bacteria. The five minutes' oxygen multiplied by 1·7 gave the amount of the available chlorine required in parts per 100,000. The machine at Guildford turned out a solution with from 0·2 to 0·5 per cent. of available chlorine, and it was therefore a matter of calculation to determine how much solution to add.

The general conclusion arrived at was that, with a good effluent, absolute sterility can be insured by the addition of 5 parts per 100,000 of available chlorine; but that for discharge into a stream used for a public water supply, one-tenth of this quantity would be sufficient.

Chlorine compounds are, apparently, the cheapest sterilisers at present available, and "chloros," which is a chemically produced solution of sodium hypo-chlorite, containing 10 per cent. of available chlorine, was used by the Metropolitan Water Board for sterilising the effluent from the Hertford Sewage Works, which is discharged into the River Lea above the intake; and the same solution was used for the Lincoln water supply during the epidemic of typhoid in 1905.

Sodium-manganate has also been used as a steriliser, and ozone is another available medium. If a sufficiently economical process of producing ozone from atmospheric air were perfected, it might be even cheaper than the chlorine compounds.

The question of sterilising storm-waters is one of great importance. It will be recognised that the scouring action, due to heavy flushes of storm-water, brings down to the purification works large volumes of deposits from the sewerage systems of most towns, and that this so-called diluted sewage is, at times of heavy rainfall, and especially early on in the discharge from a big storm, of great impurity. The general tendency of modern opinion is now in favour of largely increasing the detritus tankage for storm-waters; and some authorities go further, and

say that the storm-water should be impounded in tanks, and, if necessary, the effluent therefrom should be sterilised.

There is another class of effluent which requires sterilisation, namely,

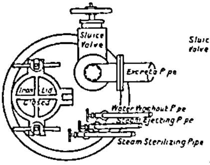


FIG. 487.

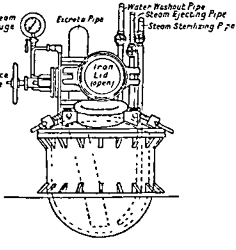


FIG. 488.

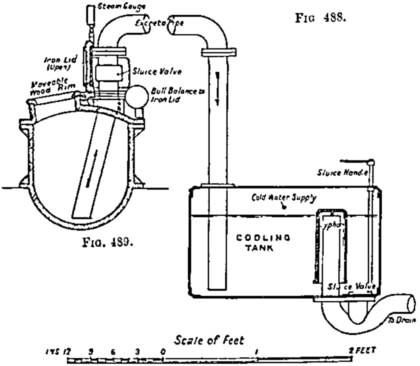


FIG. 489.

FIGS. 487—489.—The "Newcastle" Sewage Steriliser.

that from Infectious Diseases Hospitals. In this case the sterilisation should take place at the earliest possible moment.

The **"Newcastle Steriliser"** is shown in Figs. 487—489, and is made by Messrs. Goddard, Massey & Warner.

It consists of a cast-iron pot of 30 gallons capacity, with an opening

9 inches in diameter at the top; this opening being closed by a hinged and balanced lid, with rubber joint ring, made steam-tight by pinching screws. Steam is conveyed into the pan by a small pipe reaching to the bottom. There is also a second steam pipe, which conveys steam to the space above the liquid. A third pipe allows of cold water being run into the pot for cleansing purposes. Through the cover passes a larger cast-iron pipe, which reaches to within a short distance of the bottom of the pan and is closed by a valve. This pipe communicates with a cooling tank outside the building. Into this cooling tank cold water can be run to cool down the ejected sewage to below 100° Fahr., and it is then allowed to run to the sewer.

This sterilising apparatus is made purposely of small size, so that a separate steriliser can be supplied to each ward of the hospital, and it is fixed in a small annex connected to the ward. The nurses empty the bed-pans or any vessels containing infected washings or suspected liquid into the pot; the lid is then closed, and as often as necessary an attendant screws up the lid and opens the steam-cock. The steam enters at the bottom of the liquid, mixing it thoroughly and rapidly, raising it to a temperature of 250° Fahr., which is indicated by a steam gauge showing a pressure of 30 lbs. Steam is then shut off, and after the pressure has fallen a few pounds, the outlet valve is opened and the whole of the liquid is at once discharged into the cooling tank by the pressure of the remaining steam, the pan being completely emptied. The whole operation does not occupy more than ten minutes.

The Horsfall Destructor Company also manufacture a steam sterilising apparatus for use at Infectious Diseases Hospitals. This apparatus is of a larger size, and intended to deal with the sewage after it has passed through the drains and not, as in the previously mentioned apparatus, with the infected matter before passing into the drains.

This apparatus is shown in Plate LVIII., p. 688. The sewage is admitted through a 4-inch pipe into a spherical cast-iron vessel, in which it is subjected to the direct action of high pressure steam. Steam from the boiler is turned on, and passes into the steriliser from the bottom, thus distributing itself throughout the sewage and subjecting every particle of it to the high temperature.

Suitable gauges are fitted for measuring the temperature of the sewage and the pressure in the vessel, and a safety valve is also fitted to guard against any over-pressure.

When the contents have been sufficiently subjected to the high temperature, the steam inlet at the bottom is closed and the steam inlet at the top of the vessel is opened and also the sewage outlet. The

pressure of steam on the surface of the sewage forces it out of the steriliser and into a cooling tank.

The steam and outlet valves are now closed and the steam pressure allowed to escape by a blow-off pipe, and the vessel is again filled with sewage. The entering sewage condenses the steam in the vessel and this causes a rapid flow of the sewage to fill the steriliser.

An improved design for a similar steriliser, prepared by Mr. G. A. Hart for the Leeds Corporation Infectious Diseases Hospital, is shown in Plate LIX. opposite.

CHAPTER XVIII.

DISPOSAL OF SEWAGE SLUDGE.

THE final disposal of the sludge resulting from sewage purification has always been one of the chief difficulties of the problem of sewage treatment. The manurial value of the material is small, and it is a waste product of the process which must be got rid of as cheaply and as expeditiously as possible.

The methods of doing this may be briefly summarised as :—

(1) Removal to sea.
(2) Earth burial.
(3) Cremation.
(4) Drying in lagoons.
(5) Drying in prepared beds.
(6) Filter pressing.

The Quantity of Sludge per million gallons of sewage varies with the quality of the sewage, and the process adopted for the separation of the solid matter therein. This subject has already been dealt with to some extent in the article on Removal of Suspended Solids, p. 629 *et seq.*

The method of estimating the quantity of sludge from a given process is as follows :—

To the average number of grains per gallon of solids in suspension in the sewage add the grains of precipitant applied, and deduct from the total the grains of solids in suspension in the tank effluent; this gives the grains of solid matter deposited from each gallon of sewage.

Then if G = grains per gallon as above determined.
" M = sewage per day in million gallons.
" T = tons of wet sludge per day (90 per cent. water).
" P = percentage of water in pressed cake.
" C = tons of cake containing P per cent. water.

Then $$T = \frac{100\ M \times G}{154}$$

$$C = \frac{10\ T}{100 - P}$$

Pressed sludge cake containing 50 to 55 per cent. of water weighs about 14 cwts. per cubic yard.

Removal to Sea.—The removal of sludge to sea is obviously confined to those towns where there are facilities for easy shipment, and is practically limited to seaboard towns, except in the case of Salford, which is referred to on p. 713.

London and Dublin are examples of this method of sludge disposal.

At the northern outfall works of the London County Council at Barking the whole of the sewage from the north side of the river Thames is concentrated, the daily dry-weather flow being 131,000,000 gallons, which is about 40 gallons per head of the population. The sewage is precipitated in tanks holding collectively 20,000,000 gallons, or about $2\frac{3}{4}$ hours sewage flow during the period of maximum discharge after making allowance for tanks out of work for cleansing.

The chemical treatment consists in the addition of four to five grains of lime per gallon of sewage and one grain of proto-sulphate of iron in solution.

The sludge from the precipitation tanks is first pumped into sludge tanks in which it is allowed to settle, the liquor being drawn off by falling weirs, the final sludge containing about 92 per cent. of moisture.

This sludge is pumped into steamers and transported to Barrow Deeps, about fifty miles from the outfall works, by special sludge steamers, each of 1,000 tons carrying capacity, the quantity disposed of being about 31,500 tons per week, one ton of sludge being extracted from about 31,500 gallons of sewage.

The cost of precipitating the sewage and conveying the sludge to sea, including account of capital expenditure, was for the year 1906 £1 8*s*. 2*d*. per million gallons. The cost of sending the sludge to sea was 3*s*. 7*d*. per ton.

The County Council possess a fleet of six steamers for use at the Barking and Crossness outfall works.

The Dublin sewage has a dry weather flow of from $12\frac{1}{2}$ to 14 million gallons per day, which is precipitated with four grains of lime per gallon in tanks having a capacity equal to 60 per cent. of the dry-weather flow, the tank effluent having only five grains of solids in suspension.

The quantity of sludge produced is about 350 tons per day, containing 92 per cent. of water, and this is removed by sludge steamers and deposited in the Irish Channel.

Earth Burial is carried out by digging trenches in the ground and running the sludge into them, allowing a short time for drainage, and then covering the trench over with the excavated soil. This is an

excellent system where land of a suitable open character is available, and it is carried out most successfully at the Birmingham Sewage Works and many others.

Cremation is adopted at Ealing, Bolton, Huddersfield and Wimbledon: the sewage is precipitated by lime, the sludge is partially dried in lagoons and has then mixed with it an equal bulk of ashes and house refuse. The mixture is then dry enough to be easily handled, and is burnt in a refuse destructor in conjunction with dry house refuse. The refuse collected in the town of Ealing is sufficient to consume the whole of the sludge produced at the sewage works.

Drying in Lagoons is the system which is often adopted at works where sufficient land is available, and it is without doubt the least satisfactory method, its only merit being cheapness.

The sludge, which contains usually about 90 per cent. of water, takes months to dry to a sufficiently stiff consistency to be dug out, and it is then difficult to dispose of, as its manurial value is so small that farmers and market gardeners will not cart it away even if no charge is made for it.

There cannot be a doubt that the large expanses of putrefying matter, the homes of countless bacteria, which are found at many works, are a menace to the health of the surrounding districts, and the Sanitary Authority which adopts such a system cannot be said to have dealt with its sewage problem.

Drying in Prepared Beds is a great advance on the lagoon system and involves very little extra expense. The beds may be of very simple construction, as they need not be made watertight. A thin floor and sloping sides of concrete are quite sufficient, and on the floor should be laid a system of drainage made of land tiles; the pipes can be covered with gravel or clinkers, and on this should be put about six inches of fine ashes or clinkers.

The sludge should be run into the beds to a depth of 6 to 9 inches and allowed to drain. The drying process going on by drainage as well as by evaporation is comparatively rapid, and the sludge can be dug out and carted away to spread on land in the course of a few days.

The effluent draining from the beds can be irrigated upon land at a lower level, or in the absence of this must be taken back to the sewers.

Filter Pressing is the most approved system in most cases and is adopted on a large scale at Bradford, Leeds and many other towns, the cost varying from 1*s.* 6*d.* to 2*s.* 6*d.* per ton of cake produced.

Sludge precipitated with lime usually requires additional lime to be added before pressing, amounting to from ½ per cent. to 1 per cent. by

weight of the wet sludge. Septic tank sludge is very difficult to press and requires from 3 per cent. to 5 per cent. by weight of lime to be added, and even then the cakes are not satisfactory; the pressing process is slow and the wear and tear on filter cloths is excessive.

A filter press consists of a number of narrow cells held in a suitable frame, the interior faces being provided with appropriate drainage surfaces communicating with an outlet, and covered by a filtering medium, generally jute or hemp canvas, or other suitable material. The interiors of the cells so built up are in communication directly with each other, or with a common channel, for the introduction of the matter operated upon, and as nothing introduced into the cells can find an exit without passing through the cloth, the solid matter fills up their interior, the liquid leaving by the drainage surfaces. The cells of the machine are subjected to pressure, which increases as the operation goes on. The cells must of necessity be made mechanically true to the outer touching surfaces, so as to prevent the material operated on escaping as the pressure increases.

An elevation of a filter press plate, and a section of three such plates as made by Johnson, are given in Figs. 1 and 2, Plate LX. They may be either circular or rectangular in shape.

The arrangement of plant, Plate LX., is capable of dealing with the sludge (about 30 tons daily) from a population of 30,000, comprising the following apparatus:—Air compressor, air accumulator, two sludge filter presses, 3 feet diameter; two sludge forcing vessels with their fittings, and the various distributing pipes for sludge and air; a tip-truck and tramway for the removal of the pressed cake discharged from the machines.

The cost of such a plant with the requisite boiler power (about 10 horse-power actual) is about £1,000. Thirty tons of wet sludge can be easily pressed into cakes containing 50 per cent. of moisture, equalling 6 tons, or one-fifth of the original bulk, consisting of five charges from each machine, of 12 cwt. each in 10 hours.

In Leeds with a dry weather flow of $17\frac{1}{2}$ million gallons of sewage precipitated by means of 5·6 grains of lime per gallon, reducing the suspended solids to 5 grains per gallon, there is an average production of 800 tons of wet sludge per day. This quantity is dealt with by eight presses of 1-ton capacity each, and the production of sludge cake is 180 tons per day containing about 55 per cent. water.

The cost of the operation, determined from actual work extending over two years at Coventry, amounts, with all expenses included, to 6*d.* per ton of wet sludge or 2*s.* 6*d.* per ton of pressed cake.

The arrangement adopted at Wimbledon Sewage Works, by which the sludge is run off from the settling tank into the sludge reservoir,

from which it gravitates into the iron receivers, each of which contains one charge, is shown in Plate LXI. (facing p. 694). A small quantity of lime, varying from $3\frac{1}{2}$ to 5 per cent. of the volume of the sludge, is then thoroughly mixed with it, and air at a pressure of 60 lbs. per square inch is applied at the surface of the sludge, by which it is forced up the dip pipe (see Plate LXI.) and into the presses, where

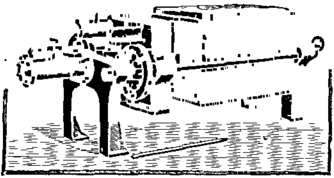


FIG. 490.—Manlove, Alliott & Co.'s Filter Press (Open).

the separation of the liquids from the solids is effected. The operation *of filling the press and removing the sludge cake takes about one hour.* By this arrangement every five tons of wet sludge, containing about 90 per cent of water, can be deprived of the bulk of its moisture, giving a residue of one ton of hard-pressed cake, containing 50 per cent. of water. The cake so obtained is easily handled, is practically inodourous, becomes air-dried rapidly, and does not again enter into fermentation. To reduce the water in the cakes, they may be loosely stacked on racks in a shed open to the wind, but secure from rain; or they may be dried upon drying floors, in kilns: such a process, however, increases the cost, and is seldom resorted to.

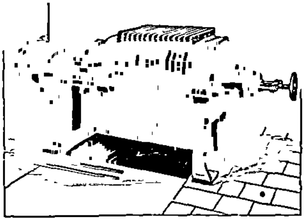


FIG. 491.—Manlove, Alliott & Co.'s Filter Press (Closed).

Messrs. Manlove, Alliott & Co.'s filter press (Figs. 490, 491) is of recent design, and possesses some improvements, the chief of which is that the wheel to be worked by hand is superseded by a small cylinder,

the piston of which is worked by compressed air, which it is c economises time in opening and closing the press.

There are several other makers of sludge presses, such as Mr. Wolstenholme, Messrs. Goddard, Massey & Warner, Ashton Frost and others.

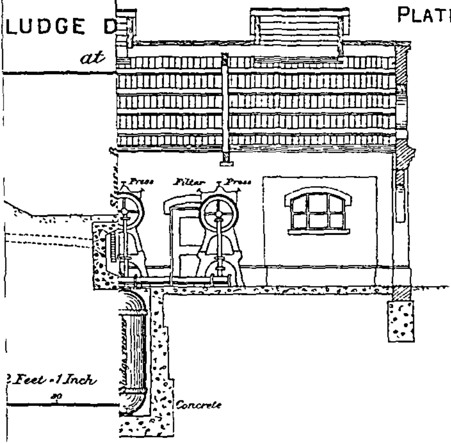
Johnson & Hutchinson's Patent Pneumatic System.— patentees have devised a system of operating the whole o machinery in a sewage works by means of vacuum or compress and by combining an oil engine with a set of high and low-pr compound air pumps and vacuum pump, uniting all in a machine (Plate LXII.) opposite. A low-pressure air service fro low-pressure air pump is employed to work the various chemical r for the treatment of the sewage and the liming of the sludge o principle of their patent pneumatic mixers. High pressure comp air is used for forcing the sludge into the sludge presses, as has hi been usual, and by the employment of a vacuum arrangement dispense with the use of sludge pumps, making use of the pneu forcing receivers as a substitute. The patentees claim that the t mission of power is of the simplest character, being of simple pipe valves. There are no machine moving parts, and as a result the and tear is reduced to a minimum. The manufacturers are M S. H. Johnson & Co.

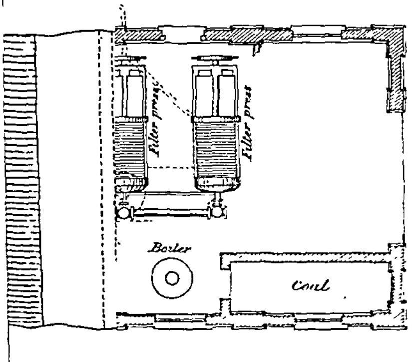
The Lifting of Sludge may be done by ordinary pumps o pneumatic pressure. Very wet sludge can be pumped by a centri pump, but plunger pumps are better in ordinary cases. Air press by far the most reliable method and gives less trouble than any system and should be adopted when installing filter presses.

PLATE LXI

LUDGE D

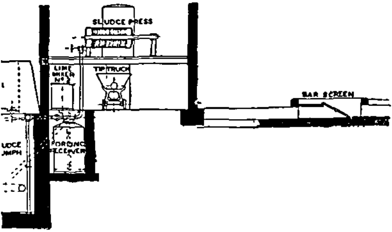
at

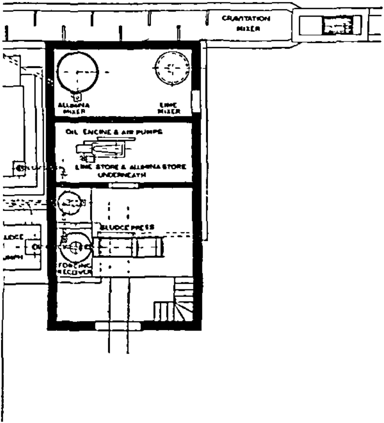




EWAGE DISPOSAL WORKS FOR A SMALL TOWN.

HUTCHINSON'S PNEUMATIC SYSTEM.





CHAPTER XIX.

DESCRIPTION OF EXISTING PURIFICATION WORKS.

SOUTHAMPTON SEWERAGE (PLATE LXIII., P. 698).

THE general arrangements of the new scheme for Southampton are illustrated in Plate LXIII. The engineer was W. B. G. Bennett, M.Inst.C.E.

The combined area of the town over which these new works extend is 2,807 acres, divided into districts as follows:—

	Acres.	Population.
Eastern district	541½	15,000
Central or platform district	303	15,000
Western districts, which include the districts of Shirley and Freemantle and part of Millbrook added to the borough in 1895 ...	1,963	25,000

The Northern District, Portswood and Bevois Town, are not included

direct to two of Shone's ejectors, installed in a chamber below the floor of the tanks; these ejectors raise and discharge the sludge into a chamber in the press house, where it is thoroughly screened and treated with milk of lime before passing to reservoirs in which it is allowed to precipitate, and the top water drawn off by floating arms, after which it is discharged into two ejectors working automatically, and continually forcing it into three sewage sludge presses, under a pressure of 60 lbs. to the square inch, which is found sufficient to produce a good cake satisfactory to agriculturists who purchase it at 2*s.* per cart load. The water drawn off the sludge falls back into the sewer, and is remitted to the tanks; the clarification of the sewage is found to be enhanced when this operation is in progress.

The sealed sludge main and valves previously referred to, are placed in a subway between the tanks, an arrangement which affords ready access to them at all times without delaying the process; above the subway the sewage inlet channel is constructed from which over weirs controlled by penstocks the sewage falls into the tank compartments. In the division walls overflows are arranged at levels which permit of the sewage being treated either by the continuous or absolute rest system. The inlet channel is decked over, forming a walking way, and upon either side of the same are placed the hand wheels of the penstocks and valves, thus giving the tank attendants command over the whole series of compartments.

This portion of the scheme includes main engine house and pump wells; penstock, screen chambers, mixing culvert and stores; installation of engines and machinery; air compressing engine house and sludge press house.

The pump wells and screen chambers, which are in duplicate, have been carried down to a depth of 27 feet below the floor of the engine house, in Staffordshire blue brick in cement, backed with Portland cement concrete.

from which the pumps lift the sewage after screening 20 feet, and deliver it into the mixing culvert on the north-east side externally, where the chemicals are added.

The re-agent at present used is aluminoferric in block, but the exact nature and quantity of chemicals to be used when the whole volume of sewage of the borough is received at the works is under investigation and in the experimental stage by the borough analyst, Mr. J. Brierly.

The mixing culvert has a double invert with sharp falls, the reverse ways and three steps; by this arrangement the sewage is caused to race and tumble before entering the conduit leading to the precipitating tanks. Provision has been made for fixing in this culvert two steam-driven rapid mixers, but up to the present time the incorporation due to the racing and tumbling, supplemented by the velocity of the discharge from the pumps into the culvert, has been effectual.

Installed in the engine house are three compound condensing Worthington sewage pumping engines, each with four steam cylinders, namely, two high and two low pressure, arranged side by side; the valve gear is so adapted that in operation the piston rod of one side moves the steam valves on the cylinder of the other side, the action is reciprocating, and the flow of the suction to, and the discharge from the pumps, is uniform and constant.

The pumps are of special construction for pumping sewage, their valves and general arrangement of pump work such as is most suitable for that purpose. They are internal plunger pumps, double action of both suctions and delivery, and consist of two distinct plunger chambers arranged in one pump case, with the plungers coupled direct to prolongation of the piston rods; each engine and pump is capable of emptying the wells at the rate of 2,200 gallons per minute; one is sufficient for the night work, two being required during the day, and the third to meet emergency.

The maximum quantity of sewage lifted from the districts at present discharging into the wells has reached 2,781,000 gallons in twenty-four hours; a daily record of the duty performed by the whole of the machinery at these works is correctly kept by the superintendent.

The air-compressing engine house contains a pair of horizontal condensing steam engine compressors, with air cylinders 20 inches in diameter by 24 inches stroke, arranged so as to work either independently or coupled together, each of the compressors being capable of doing the whole work if necessary.

This plant is used for operating at the present time nine Shone's ejectors, located in various districts of the town.

The greatest distance air is transmitted from the works is nearly two and a-half miles. The maximum pressure these engines have been

required to supply for the present works is 30 lbs. to the square inch, and the steam pressure 40 lbs.

For the sludge pressing a pair of compressors have been provided and installed in the same building capable of supplying air at 90 lbs. per square inch. These are of the same type as the others, but with air cylinders 9 inches in diameter by 14 inches stroke, also arranged to work coupled together, but each is capable of doing the maximum work alone when necessary.

The sludge press house contains three square framed filter presses, with space provided for future addition, each press containing 30 chambers, 38 inches square, with corrugations in the surface of the plates, which are provided with an outlet for the discharge of the filtered water from the sludge. The presses are proportioned so as to be capable of working under a pressure from 90 to 100 lbs per square inch, the capacity being 1 ton 8 cwt. at each operation per press. The presses are provided with pneumatic cylinders, and piston rods for opening and closing them; a tramway with trollies is laid to facilitate removal of the cake.

The record previously mentioned shows that the maximum output of cake has reached 18 90 tons from 94 50 tons of wet sludge per day.

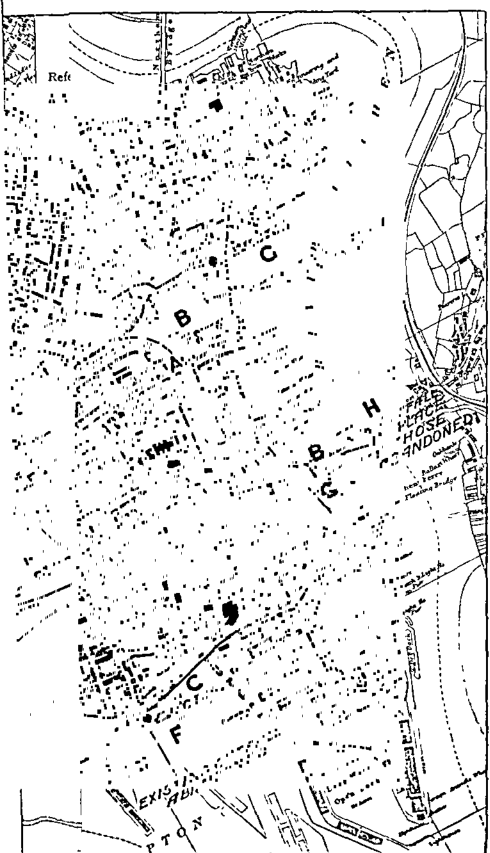
The sludge before pressing is dosed with milk of lime prepared in two Bowes-Scott lime mixers fixed in the press house, and driven by a small steam engine; the lime is supplied in powder and fed into the mixers from an adjoining store in regulated quantities by a small endless chain elevator. From the mixers the milk of lime flows into two hoppers connected independently to the sludge inlet pipes of the ejectors before mentioned, the operation being that upon either ejector drawing a charge of sludge from the reservoirs a dose of milk of lime is administered at the same time, and the combination ejected into the presses; so soon as one press is fully charged the attendant diverts by a hand valve the flow into another. The ejectors, being automatic in their action, greatly facilitate the process.

The time occupied in charging, pressing, and removing the cake does not exceed 40 minutes, and the pneumatic cylinder for opening and closing the presses is found to work with great advantage. The quantity of lime used at each pressing is found to be 70 lbs.

The steam required for the operation of the various engines is obtained from the refuse destructor of 10 cells adjoining the pumping station.

The main intercepting sewers follow nearly the line of contour round the eastern, southern, and western fronts of the town, and are delineated on Plate LXIII., opposite, and referenced under the letters, B B B B, C C C, D D D D D.

The chief sewers are of the following dimensions, starting from the Pump Wells :—136 yards of 4 feet 6 inch by 3 feet egg-shaped; 117



yards of 4 feet by 2 feet 8 inch egg-shaped; 426 yards of 3 feet 6 inch by 2 feet 4 inch egg-shaped; 130 yards of 30 inch Hassall's double-jointed pipes on concrete; 763 yards of 24 inch Hassall's double-jointed patent pipes on concrete; and subsidiary to the before-mentioned, 1,300 yards of 18 inch, 15 inch, 12 inch, and 9 inch.

As far as possible the old sewers have been retained as rainfall sewers and they have been supplemented by additional new rainfall sewers, all of which discharge above tide level by gravity, except at the platform where the old tanks are retained for the storage of the rainwater during tide time; and the discharge is also assisted by an ejector.

For the drainage of the western district towards the new disposal works a new intercepting sewer D D has been constructed as follows:—666 yards of 3 feet 6 inches by 2 feet 4 inches egg-shaped brick sewer, as before described; 540 yards of 30 inch cast-iron pipe, and 820 yards of 27 inch cast-iron pipes laid on a bed of concrete; 500 yards of the work is in tunnel under a higher portion of the town, commencing from the Western shore, 100 yards south of the Public Baths, and proceeding across in an easterly direction to the lower ground.

A portion of this district beyond Shirley and Freemantle, 982 acres, was unprovided with means of sewerage or sewage disposal at the time of annexation, but under the scheme this has been thoroughly sewered and storm-water drained. Upwards of 4¾ miles of stoneware and cast-iron pipe sewers have been laid, consisting of 18 inch, 15 inch, 12 inch and 9 inch, the stoneware pipes being Hassall's as before.

As the levels of this district will not permit the sewage to gravitate to the one place of disposal, two of Shone's ejectors of 500 gallons capacity have been put down in cast-iron tubing ("F" on map), with provision for additions; this sewage is raised by this means and discharged into the gravitating sewer, D D., *which discharges into the* new sewer at the West End Railway Station.

Glasgow Sewage Works (Plates LXIV., LXV., p. 704).

The following description of the main drainage undertaking of Glasgow has been compiled from information kindly supplied by the city engineer, Mr. A. B. McDonald, M.Inst.C.E., designer of the works, and has been checked by him.

There are three separate works dealing with the sewage of a very large area within and outside the city of Glasgow; they present an excellent example of well designed and managed works which turn out an effluent of sufficient purity to be discharged without possible objection into a tidal river with from thirty to fifty times its volume of flow.

The territory included in the scheme stretches along both sides of the river Clyde for a distance of about 15 miles, the superficial extent of the

drainage area being 39 square miles. This territory may hereafter be increased by the inclusion of areas belonging to outlying local authorities.

The volume of sewage and the proportion of rainfall to be dealt with, which originates within the indicated drainage area, and which will be treated in the three separate works described, is estimated, on the ultimate development of the whole territory, at 250,000,000 gallons per day.

The drainage area is divided into three sections, each distinct from the others, with separate works for the disposal of their sewage.

The first of these is situated in the eastern district of the city, and comprises about 11 square miles, one half being within Glasgow and the remainder in the landward district of the county of Lanark. The works for the treatment and disposal of the sewage of this area are situated on the river bank at Dalmarnock.

The second or western section comprises the municipal area of Glasgow on the north side of the river, not dealt with at Dalmarnock, the burghs of Partick and Clydebank, and intervening parts of the counties of Renfrew and Dumbarton, the whole extent being 14 square miles.

The works for the disposal of the sewage derived from this area are situated on the river bank at Dalmuir, about 7 miles below Glasgow.

The third or southern section includes the whole municipal area of Glasgow on the south bank of the river, the burghs of Rutherglen, Pollokshaws and Govan, as well as various residential and rural districts in the counties of Lanark and Renfrew. The extent of this section is 14 square miles.

The works for the disposal of the sewage of this area were originally intended to be situated on the river bank at a place named Braehead, about 1 mile eastward from the burgh of Renfrew. It having been found later on that this site would conflict with the policy of the trustees of the Clyde navigation, it has been arranged to place the works at Shieldhall, nearer the city.

The collecting and intercepting sewers which connect with the Dalmarnock Works are all constructed, and have been in successful operation since May, 1894.

The daily volume of dry-weather sewage treated there at the present time is about 16,000,000 gallons, which, when the locality is fully developed, will be increased to 20,000,000 gallons.

The daily volume of dry-weather sewage to be ultimately treated at Dalmuir is 49,000,000 gallons, and the corresponding volume at Shieldhall will be 47,000,000 gallons.

In addition to the daily dry-weather flow of sewage an amount of rainfall equivalent to ¼-inch per day will be conveyed in these sewers, making a total of 210,000,000 gallons of combined discharge at Dalmuir and Shieldhall.

Regulating valves placed in the main sewers control the admission of this proportion of the rainfall; any excess passing to the river by means of the ordinary sewers as at present. When unusual conditions necessitate the admission of a larger volume of rainfall special arrangements are provided on the main sewers at convenient intervals for relief of storm-water.

The method of purification adopted is the same in each of the three works, viz: chemical precipitation. At the Dalmarnock Works the purified tank effluent was originally passed through coke filters, but the use of these has for some time been discontinued.

The following particulars refer to the Dalmarnock Works which are illustrated on Plate LXIV., p. 701, but with certain modifications are applicable to the Dalmuir and Shieldhall Works.

The sewage on arrival at the Dalmarnock Works flows into two catchpits, each of which is 47 feet 10 inches long by 20 feet broad and 10 feet deep. The bottom of the catchpits at the elevator trough is 28 feet 6 inches below the floor line and slopes up to the end walls, thus enabling the soft materials to gravitate to the elevator trough, the bottom of which is 33 feet 6 inches below the floor line. The solids are here raised by the elevator buckets into a railway waggon on the floor level. Each catchpit can be worked separately as may be required. The sewage, freed in this manner from heavy matters, flows from the catchpits into a 10 feet channel on the east side, leading to the pump well, the depth of which is 31 feet 1 inch below floor line.

The suction pipes from the centrifugal pumps are led down to within 15 inches of the bottom of the pump well. The water is raised through these into a 3 feet 9 inches cast-iron pipe placed against the south wall of the pump-room, through which it flows into the mixing pit, where the chemical ingredients are introduced.

The sewage received at Dalmarnock Works is of a very complex and intractable character, consisting principally of industrial refuse carrying suspended matters that vary from 20 to 1,000 grains per gallon. The treatment of such sewage is a matter of no ordinary difficulty, and the proportion of the chemical ingredients undergoes frequent change during the day.

Sulphate of alumina and lime are the precipitating agents used, in the proportion of 2 of alumina to 1 of lime. The quantities used vary, as has been said, according to the varying character of the sewage.

There is one 24 inches, two 18-inch and two 15-inch pumps with a total of 530 horse-power, capable of raising 2,000,000 gallons per hour. Two 6-inch pulley pumps on the east side of the pump-room discharge the sewage into the lime mixers placed over the sludge tanks. This liquid is used for making milk of lime and dissolving the sulphate of alumina.

These pumps are driven from the main line of shafting which is worked from the engine-room, where there are two pairs of compound condensing

engines, each of 120 horse-power. The precipitated sewage water is used for the condensers. These engines drive all the shafting. There are two dynamos, either of which can supply light for the whole works.

The sewage is delivered at the mixing-pit, which is 10 ft. × 10 ft. × 8 ft., with a centre tongue going down to within 3 feet 6 inches from the bottom: the sewage mixed with the chemicals passes under this tongue into an outlet channel 8 ft. × 3 ft. 6 in. leading to the feed channel of the precipitation tanks.

There are four large tanks worked on the under-surface continuous flow system. These combined have a surface area of 15,602 square yards, and a capacity of nearly 5,000,000 gallons. It has been found that over 5,000,000 gallons can be satisfactorily precipitated for every million gallons of tank capacity. There are also eighteen smaller precipitation tanks each 100 ft. × 50 ft. with a storage capacity of 34,200 gallons; these were originally worked intermittently, but have been altered, and now work on the under-surface continuous flow system. The clear effluent is drawn off from the tanks by water drainers.

The residual sludge is drawn from the precipitation tanks by 12-inch disc valves into underground conduits varying in size from 3 feet 3 inches to 6 feet 6 inches with a fall of 1 in 400 delivering into a sludge tank below the sulphate of alumina room, at a level of 17 feet 4 inches below the floor line.

The liquid sludge is raised from this tank by a 6-inch centrifugal pump into three sludge settling tanks and allowed to precipitate. When 50 per cent. of the water has been run off into the pump-well the precipitated sludge is drawn from these tanks into another tank 46 ft. × 40 ft. × 23 ft. below the floor-line under the lime mixing-room. In the north-east corner there is a low-pressure sludge ram 29 feet below the floor-line capable of holding 1,800 gallons, through which the sludge is raised by compressed air into the two sludge mixers at the east wall of the lime-room. Here hot lime is added to the sludge to facilitate the pressing.

In the lower floor of the sludge receiving-room there are four high pressed rams, each holding 900 gallons. The sludge runs from the mixers by gravitation through a 6-inch cast iron pipe into these rams, from which it is raised by compressed air at 100 lbs. to the square inch into the sludge presses. When this air has blown the sludge from the high pressed rams it is transferred into the large low pressed ram in the north-east corner of the sludge tank, thereby effecting a saving of fully 80 per cent. of compressed air, by raising sufficient sludge into the mixers to again re-charge the high-pressed rams. To duplicate the high-pressed rams there is a horizontal duplex pump with 11-inch cylinder, $7\frac{1}{4}$-inch pump, 10-inch stroke, capable of discharging 50 tons

per hour of crude sludge against 100 lbs. pressure. This pump can draw direct from the sludge well or from the sludge mixers. The air is compressed by two high-pressure engines, and there is also a duplex steam pump for feeding water into the boilers.

In the press room on the top floor, there are 12 sludge presses, seven of which hold 25 cwts. each, and five 32 cwts. each, when fully charged, making a total of 16 tons 15 cwts. of pressed sludge cake each round of the presses. This sludge cake is dropped through shoots in the floor into railway waggons placed immediately underneath. By passing the sludge cake through a patent drying machine, the moisture can be reduced to 15 per cent. It is then passed through a 7-feet mill with a perforated bottom, prior to being filled into bags, or loaded direct by elevators into railway waggons. This product is called "Globe Fertiliser Sewage Manure."

The pressed sludge contains about 60 per cent. of moisture and the "Globe Fertiliser" about 16 per cent. of moisture. These products are loaded direct into railway trucks and despatched to farms wherever there is a demand for them; at other times they are stored on the works or sent to the corporation farms.

The population draining to these works was estimated at 290,000 in 1907. The total area of the site of the works is about 28 acres of which 19 acres are at present in use. The land cost £35,462 and the buildings, tanks and machinery cost £101,257, making a total of £136,719.

Table No 117 gives particulars for two years of the work done at those works, the population draining to the works in 1903 being 276,000 persons.

TABLE 117

—	1901—1902		1902—1903	
Total sewage dealt with	5,359,224,000 gallons		5,220,673,216 gallons.	
Average daily quantity	14,682,805 "		14,303,159 "	
Average cost of chemicals	£0 10 3 2/10		£0 8 5 2/10	
Crude sludge extracted by precipitation	220,732 tons.		209,140 tons.	
	Tons	Cwts	Tons	Cwts
Sludge cake from filter presses	31,161	18	31,419	14
Sludge raised by elevators	743	13	1,340	4
Total solids .	31,905	11	32,759	18
	Tons	Cwts.	Tons.	Cwts
Deposited on ground at works	3,169	4	5,451	16
Sold as manure by sewage department	16,612	14	14,211	7
Manufactured into "Globe Fertiliser"	1,095	16	5,487	4
Despatched by rail to refuse tips	11,027	17	7,609	11
	31,905	11	32,759	18

Table 118 gives the cost of sludge pressing for the same two years.

TABLE 118.

—	1901—1902.	1902—1903.
	Per ton £ s d.	Per ton. £ s. d.
Cost of pressed sludge cake	0 2 $5\frac{2}{10}$	0 2 $3\frac{4}{10}$
Cost of sending sludge cake to tips including hire of sewage department waggons .	0 1 $1\frac{3}{10}$	0 1 $0\frac{1}{10}$

Table 119 gives the working *expenses per million gallons of sewage* treated.

TABLE 119.

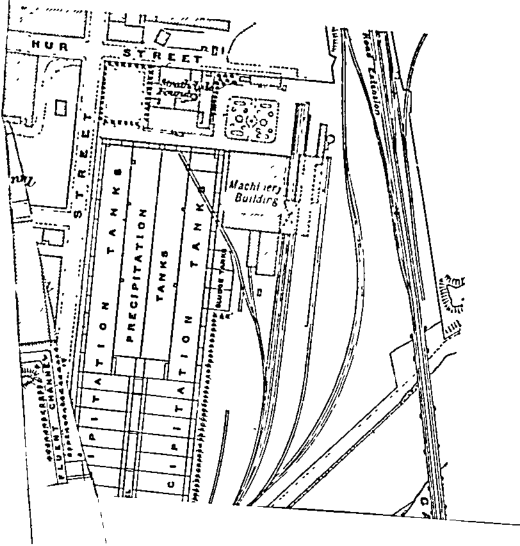
—	1901—1902.	1902—1903.
	£ s. d	£ s d
Pumping . ..	0 11 $8\frac{3}{10}$	0 13 $3\frac{4}{10}$
Precipitation, including chemicals.	0 18 $2\frac{2}{10}$	0 14 $0\frac{1}{10}$
*Filtration, including coke	0 1 $11\frac{5}{10}$	0 1 $5\frac{5}{10}$
Sludge pressing	0 14 $3\frac{2}{10}$	0 13 $8\frac{6}{10}$
Sludge to tips	0 1 $10\frac{3}{10}$	0 1 2
	£2 7 $11\frac{5}{10}$	£2 3 $7\frac{6}{10}$

After careful deliberation and much patient inquiry on the part of the sewage committee and their advisers, it was resolved to adopt at Dalmuir and Shieldhall the same method of treatment as had been proved successful at Dalmarnock, with this exception, that the sludge presses which by compulsion of circumstances at Dalmarnock Works are employed there, are dispensed with, and the precipitated sludge, without *undergoing pressure, is carried out to sea in a specially constructed* sludge steamer. The cost of recovering and despatching this sewage sludge to sea, a distance of 40 miles, is $2\frac{3}{4}d.$ per ton.

The sewage works at Dalmuir were opened on 3rd May, 1904, and have been in continuous working since that date.

The southern works at Shieldhall are not yet completed, and it is probable that the whole sewage intended to be treated there will not be connected up until 1910. When these works are installed an additional steamer will be needed, but it is claimed that experience will prove that the complete undertaking, which, next to that of the London County Council, is the largest in the world, will be more economically carried on than any other.

* This part of the process has since been abandoned.


HUR
STREET
STREET
South Yard Foundry
Machinery Building
PRECIPITATION TANKS
PRECIPITATION TANKS
PRECIPITATION TANKS
EFFLUENT CHANNEL
SLUDGE TANKS

Kingston-on-Thames Sewage Works.

The A.B.C. system is in operation at these works. The feature of this system is the combination of certain natural substances which it is claimed when added to town sewage deodorise and purify it, precipitating its impurities so as to leave the effluent water in a fit condition to flow into ordinary rivers and the precipitated deposit a valuable manure.

These substances are principally :—

Clay,
Carbon,
Blood and
Salts of Alumina.

Should the sewage be too acid, some alkali would be used to neutralise it. Should it be too alkaline, a little acid is added. These substances are used in the following manner: First the sewage is treated with a triturated mixture of clay, carbon and blood, which at Kingston is added to it in the pump-well before it is raised to the tank level. It is considered preferable to add this mixture to the sewage at the earliest possible stage after it reaches the works. These substances together act as deodorants and purifiers. Subsequently a solution of alumina is added in the channel leading from the pump delivery to the tanks. The exact proportions in which these substances are mixed and added to the sewage vary with the strength of the latter, but the average proportions may be inferred from the following figures for the materials used at Kingston :—

Clay, carbon, blood and Salts of Alumina ... Grains per gallon, 50.

When the sewage thus treated passes into the settling tanks precipitation occurs, which not merely deposits the grosser suspended matters but a large proportion of the dissolved impurities which have attached themselves, both chemically and mechanically, to the clay, carbon and blood. The resulting effluent water is rendered fit to be discharged into ordinary watercourses, and the tank precipitant is in a condition for removal and conversion into a portable manure, which is effected in the following manner :—

The precipitate in the condition of sludge, containing about 90 per cent. of water, is removed from the tanks into filter presses, which reduce it to a cake containing about 50 per cent. of water. The cake is further dried by artificial heat or otherwise until it contains about 20 per cent. of moisture, after which it is bagged ready for use.

The following information as to the Kingston-on-Thames Sewage Works was supplied by Mr. Douglas Archibald, the manager of the works in 1907.

These works were built by the Kingston Corporation, and opened in

1888, in order to carry out the A.B.C. system of sewage purification operated by the Native Guano Company. They were designed by the Borough Surveyor, Major Macaulay. Originally intended for a population of 35,000, they are being used with small additions up to date for a population estimated in 1907 as 58,000, made up as follows :—

Kingston	41,044
Surbiton	14,307
Hampton Wick	3,112
	58,463

The average daily flow of sewage during the five years preceding 1907 was about 2,509,000 gallons, which amounted to an average of 46·87 gallons per head, on the average population of 53,549 for the same period. From 1895 to 1901 it was only 39·21 gallons per head. The Kingston sewage, on reaching the works, passes into a screening chamber and through a grating, which intercepts coarse matter likely to choke or injure the pumps, and thence through a culvert to a pump-well under the main building, where it receives the "B.C.," or deodorising and purifying mixture. The sewage thus partially treated is raised about 12 feet by centrifugal pumps, of which there are three, each driven by a 15-horse-power engine, and capable of lifting 1,650 gallons per minute. The pumps discharge into a meter-chamber, where the sewage is measured and the quantity registered. On leaving the meter, the sewage flows along an open channel to the settling tanks, receiving on its way the precipitating agents. There are eight tanks, each 85 feet long by 50 feet broad, and 6 feet average working depth, holding 150,000 gallons each, or 1,200,000 gallons in the aggregate, which gives a capacity of only 20·5 gallons per head for the population of 58,463 or about half the daily flow per head.

The treated sewage flows in a continuous stream through the tanks, precipitating as it flows, and passes thence through a small area of contact beds into a channel discharging into the Thames. The tanks are cleaned periodically, the deposit or sludge being pumped into the sludge-well by a Tangye-Holman double-action pump at the rate of 500 gallons per minute. From this well the sludge is first drawn into six sludge vessels or accumulators by the creation of a vacuum, and is then forced by air pressure, at 100lb. on the square inch into filter presses on the first floor of the building, from which it is removed in hard cakes. There are three of Scott's air pumps and sixteen of the Native Guano Company's filter presses. The pressed cakes are dried in a Borwick's drying cylinder (with fan and condensing apparatus attached), ground into powder, bagged, and sold as Native Guano at £3 10s. per ton.

The Surbiton sewage is separately received and screened, and is pumped by centrifugal pumps through a meter into the Kingston pump-well. There are three pumps, each driven by an 8-horse-power engine, and capable of lifting 750 gallons per minute. Two mortar mills are used for grinding the chemicals, which are then mixed in vats, and discharged into the pump-well; and there are two vats for dissolving the precipitating agents. A small Worthington pump supplies water from the river for the boilers, mixing the chemicals, etc. To complete and supplement the above, about $1\frac{3}{8}$ acres of contact beds, varying from 1 yard to $1\frac{1}{4}$ yard in depth, were added in 1907.

The chief feature of the tank process is the addition of a considerable quantity of charcoal and clay and a small quantity of blood while the sewage is in the pump-well, and subsequently a heavy dose of dissolved sulphate of alumina after it has reached the surface. The particular *rôle* played by each individual substance is not precisely determinable, but their total effect may be stated to be.—(*a*) A purification as measured by the reduction in the albuminoid and oxygen figures of the raw sewage of from 75 to 80 per cent.; (*b*) an almost complete elimination in the tanks of all the suspended matter. The tank effluent is thus peculiarly adapted for filtration upon an unusually small area of contact or other filter bed.

Until a few years ago this tank purification alone satisfied all the Thames Conservancy requirements, even above Teddington Lock. Since 1895 the Thames Conservancy have raised their requirements for towns above Teddington Lock to a point unattainable at all times by any tank process, and the Corporation, in consequence, have laid down about $1\frac{3}{8}$ acres of contact beds, which, according to the experiments with the tank effluent made by the company, will, when filled with coke breeze, effect a further purification of from 60 to 70 per cent. The total purification on the raw sewage thus attainable with one contact therefore ranges from 90 to 94 per cent, and even then the complete works will only have cost 12*s.* per head on the population at the time the contact beds were made (1907).

The actual chemical condition of the tank effluent and the filtrate may be gathered from the results of the seven and a half years (May 24th, 1898, to September 18th, 1905) continuous working by the company of their experimental coke contact filter (Table 120, p. 708).

The rate of working on the company's coke filter during the above period varied from three to six fillings within the twenty-four hours, the average for the whole period being 3·82.

Corresponding samples from a duplicate bed filled with clinker for 722 days gave 21 per cent. less purification than that effected by the coke. Owing to the exceptional freedom of the tank effluent from

suspended matter, there is no sensible loss in the water capacity of the coke bed—at most about 8 per cent. per annum. The area—1⅗ acre—of the contact beds which have been constructed by the Corporation has been based upon the exceptional rate at which, according to the company's experiments, the Kingston tank effluent can be passed through coke beds.

Designed in 1898 for the flow at that time of 1,917,000 gallons per day, their area, with a uniform depth of one yard, would have required 288 gallons per square or cube yard, or exactly five fillings per day on a 33 per cent. capacity basis, an unusually rapid rate of filtration, and impossible with ordinary tank effluents. Owing to the delay of eight years in their construction, the same filter area has to accommodate an average of 592,000 gallons per day in excess of the original flow. In order to do this the Corporation have, in the

TABLE 120

—	Number of Samples Analysed.	Tank Effluent	Filtrate	Average Purification on Tank Effluent
Albuminoid Ammonia ..	555	0·25 part per 100,000.	0·089 part per 100,000.	65 p.c.
Oxygen absorbed in four hours, average of short period, May 4th, 1900, to September 4th, 1901.	27	1·50 grain per gallon	0·45 grain per gallon.	70 p.c.

course of construction, increased the depth of five out of the six filters from 3 feet to 3 feet 9 inches, by which the average flow of 2,509,000 gallons per day becomes 312 gallons per cube yard, and can be accommodated by 5·5 fills per 24 hours on the beds.

Unfortunately the filters have not been hitherto filled with coke breeze, and have therefore been unable to be worked efficiently at such a rapid rate. In 1907 the Corporation decided to fill one of the filters with coke breeze. With this material and some little extension to suit the increased population the degree of purification, according to the exhaustive experiments of the company, ought to suffice to meet all possible requirements.

The guano, after emerging from the drying cylinder, is stacked and sold in sacks, chiefly in the spring season. The entire year's make (about 2,300 tons now, or 1 ton to every twenty-five persons) is, on the average, sold within each year. Since the company began their working in 1888 the entire quantity made has been sold at the uniform price of £3 10*s*. per ton. Apart from the undoubtedly high proportion

SALFORD SEWAGE WORKS (PLATE LXVI., p. 914).

These works have been designed and carried out by Mr. J. Corbett, Borough Engineer, and to him belongs the credit of carrying out the earliest percolation system on a large scale in this country. The general arrangement of the works is shown on Plate LXVI., p. 914. The process is three-fold. 1st. Chemical precipitation by continuous flow in tanks. 2nd. Straining through gravel roughing filters. 3rd. Bacterial purification by aerated filters or beds, supplied through fixed spray-jets.

About one-fourth the total flow of sewage comes in by gravitation, and three-fourths is pumped from the main intercepting sewer, which is laid near the river in its winding course through the borough, crossing below the river at three places, without requiring syphons, and serving to drain the land water.

The dry weather or minimum daily flow of sewage from the borough population of nearly 230,000 is about 8,000,000 gallons, of which about 5,500,000 gallons flow between 9 a.m. and 9 p.m. and 2,500,000 gallons between 9 p.m. and 9 a.m.

The average daily flow is 12,000,000 to 13,000,000 gallons, and the greatest flow provided for is 32,000,000 gallons, or four fold the dry weather flow.

Of the 8,000,000 gallons dry weather flow, about 4,600,000 gallons are domestic sewage (the estimated quantity of the water supply), about 2,000,000 are liquid trade refuse; and the remaining 1,400,000 gallons are from subsoil water, this item increasing considerably in wet weather.

The ultimate flow provided for, 32,000,000 gallons, is 139 gallons per head of the present population.

The main intercepting sewer has a pump sump 2 feet below its invert, from which a chain bucket dredger daily lifts any deposit of silt, by steam power, into tram trucks which convey it to the sludge tanks, and so out to sea.

There are three screening chambers, controlled by valves, each with an iron grating 6 feet wide and 13 feet high, with bars $\frac{3}{4}$ inch apart. The usual raking apparatus is provided, worked by steam power.

The sewage then passes through a 45-inch brick culvert to the pumping engines.

Each of the three pumping engines has 30-inch suction and delivery pipes, separate throughout.

Two pumping engines are alike, each being a vertical compound engine, with $24\frac{1}{2}$-inch H.P. and $40\frac{6}{10}$-inch L.P. cylinders, connected to cranks at 90°, and with a double-acting pump at some distance below each steam cylinder, 31 inches diameter, all of 6-foot stroke and working up to 17 revolutions per minute.

(Originally made by Messrs. J. Watts & Co., Soho Works, Birmingham, and greatly improved by local firms.

In 1906 a centrifugal pump and vertical compound tandem engine was added, made by Messrs. Tangye's Ltd., with cylinders 17 inches and 25 inches, by 12 inches stroke, and up to 194 revolutions per minute; the fan is 60 inches diameter. Inlet and outlet 23 inches diameter.

Each of these three pumps, when in good condition, can raise 16,000,000 gallons of sewage per 24 hours, the gross lift being from 20 to 30 feet. So two engines can deal with four times the dry weather flow, leaving one engine in reserve.

There are four steam boilers, each 28 feet by 7 feet, of the Lancashire type, with Galloway tubes, worked at 64 lbs. pressure. Their furnaces are fitted with steam-jet forced draught to facilitate the use of inferior fuel.

The sewage when pumped is delivered into a mixing chamber at the east end of the tanks, about 10 feet cube, with a mixing screw 6 feet diameter on a vertical shaft. Here is connected the gravitation flow, and the milk of lime precipitant is added.

The quantity of precipitants used varies from time to time and averages about 5 cwts. of lime and 3 cwts. of copperas per million gallons of sewage.

There are sluice valves to provide for a bye-pass flow (during repairs etc.) of all the sewage along the gravitation channel to the west end of the tanks; but the usual flow is through two silt pits, one about 100 feet, the other 50 feet long, each 10 feet wide and 11 feet deep,

each with an 18-inch valve and silt discharge pipe to the sludge tanks.

Between the two silt pits is a weir, where the flow of sewage is gauged by an automatic recorder, and below this weir the dissolved salts of iron precipitant is added.

The sewage then enters the central channel, 10 feet wide, about 4 feet deep, and 550 feet long, from which it is passed into the tanks on each side by large sluices. There is a system of large sluices between the several tanks, also outlet sluices to the tank effluent channels, one on each side of the range of tanks, so that the flow can be run through all the ten tanks in series, or through groups of five, three, or two tanks, or through single tanks in parallel, any tank being shut off, emptied and cleansed when required.

The ten precipitation tanks have a total capacity of about 5,000,000 gallons, each tank being about 115 feet by 82 feet, and from 7 to 10 feet deep.

The tank effluent channels lead to a cross channel at the east end of the tanks in which are 20-inch valves for supplying each of the roughing filters, six in all, which adjoin this channel. Each roughing filter has a row of inlet holes along its west end, supplied from a chamber in the wall below the cross channel. The floor is of perforated tiles on short legs, thus forming an outlet channel leading to an outlet pipe 20 inches diameter, controlled by a valve in the valve chamber; and from this chamber three 30-inch pipes convey the effluent to the aerating filters or bacteria beds.

The roughing filter valves are arranged so as to provide for reversing the current in any one of the six filters, and thus "upward washing" it, the washing passing to the sludge tanks or to the sewer as preferred.

Also for cleansing these roughing filters, each of the six is divided by screen walls into three bays, thus forming together eighteen bays, which can be "upward washed" one by one. Each bay of about 105 square yards area has a system of air-blowing pipes fixed near its floor, through which air is blown at a pressure of 5 lbs. per square inch through 4,800 holes of $\frac{1}{8}$-inch bore, thereby disturbing the gravel and speeding the upward flow of the washing water.

These roughing filters are made of 3 feet depth of fine gravel between $\frac{3}{16}$-inch and $\frac{5}{16}$-inch diameter. They have to be "upward washed" and blown through once a day, or oftener when the flow of sewage is great. Their purpose is to remove matter in suspension and colloidal matter.

The three 30-inch pipes above mentioned are along the north of upper end of the bacteria beds, with a 15-inch branch and control valve to each of the fifteen beds first constructed, and with an 18-inch branch

and valve to each pair of the beds subsequently formed. The 30-inch pipes have also valves at their inlets, so as to control the beds in three groups.

When the first fifteen beds were designed in 1894 there was but little experience as to the durability of bacteria beds, so they were arranged with a strong tram rail supported on cast-iron pillars at each 31-feet width, each alternate line of pillars also carrying a light tram rail at 2-feet gauge from the strong tram rail, so that tram trucks of 2-feet gauge might thereby bring the filtering material to its place. A light portable bridge, with a turn-table, then carried the trucks across the width of a bed so that the material could be dropped exactly where it was wanted.

The strong rails were intended to carry a machine something like a steam power travelling crane, by which the surface of the beds could be raked, or the material refilled into tram trucks and carried away for cleansing or renewal when required.

The supply of clarified sewage to each bed passes through a 15-inch pipe at the base of the cast-iron pillars, and each pillar forms a rising branch up to a horizontal pipe 4 inches diameter, fixed above the surface of the bed at 10-feet centres, with six spray-jets across the 31-feet breadth of beds, each spray-jet serving an area 10-feet by 5-feet 2 inches. The two forms of jet in use are the "Salford" and the Harrison and Gjers Patent; see Plates LIV., Figs. 1 and 2, p. 668.

In the later constructed beds the tram rails are omitted, and the supply pipes are carried above the surface on brick pillars, with 8-inch branches right and left so as to cover a double bed of 62 feet breadth. All the distributing pipes have emptying valves and pipes leading to a sewer, to avoid risk from frost when resting.

The filter floors are of concrete, with culverts at 62 feet spaces for conveying the filtrate to the 4-foot final outfall culvert at the south end of the beds. The concrete floors are covered with perforated tiles on legs 4 inches long, so as to provide ample ventilation below the beds. The earlier beds have ventilated manholes at each end of each culvert, and the later beds have vent shafts through the brick piers carrying their supply pipes; they have also open sides allowing free air-way to or from their raised tile floors; but the earlier beds are enclosed with walls. There are no dividing walls between the adjoining beds; they form really one continuous bulk.

The filtering material is crushed cinders and clinkers, from about $\frac{3}{16}$ to $\frac{3}{4}$ inch in the earlier beds, and from $\frac{3}{4}$ to $1\frac{1}{4}$ inches in the later beds, with some coarser material at the bottom. Thirteen of the earlier beds are 5 feet deep, two are 8 feet, and the newer ones are about 7 feet deep.

Owing to these beds having been worked for several years before the roughing filters were completed and provided with cleansing apparatus, there is much more clogging of the beds than was expected; but after they have been once thoroughly cleansed it is expected that they will require but little renewal or cleansing in future years. Their surface is raked by hand labour each few days.

The spray-jets, when working under the full available head of about 8 feet, deliver at the rate of 50 gallons per square yard per hour, or 1,200 gallons per twenty-four hours if run continuously. There are 39,000 square yards of beds, so that each hour's flow of all the spray-jets will discharge 1,950,000, say 2,000,000 gallons. So with the minimum or dry weather flow of 8,000,000 gallons per day, each bay must be *worked about four hours and rested twenty hours; and with the maximum* flow provided for, viz., four-fold the minimum flow or 32,000,000 gallons per day, each bay must be worked sixteen hours and rested eight hours; but the working hours can be extended if desired by checking the flow by the control valves.

It has been found best to run each bed for two hours and then rest it for ten hours or less, according to the quantity to be dealt with.

Thus the minimum daily flow per square yard of bed is about 205 gallons, the average about 330 gallons, and the maximum 820 gallons; but this large flow will only occur when the sewage is greatly diluted with rainwater

As the beds average 2 yards in depth, these flows are only, per cubic yard of medium, 103 gallons per day minimum flow, 165 gallons average, and 410 gallons maximum flow when diluted with rain-

Then one length of pipe can be raised and the water run down 2 feet above the outlet level; and the flow along the subway channel is all this time turned into the main sewer. But when the second pipe is raised and the sewage sludge deposited on the tank floor begins to flow, the channel is connected to the sludge tanks.

There are two sludge tanks, circular and saucer shaped, 100 feet diameter and 9 feet deep in the middle; the two holding 3,000 tons of sludge. There is a supply channel around each sludge tank with holes through the wall to distribute the sludge. There is also a sludge supply trough extending to near the centre of each tank. From the centre of the tank bottom an 18-inch suction pipe leads to the sludge pumps; and also at the centre is a 6-inch skimming pipe leading to the sewer, and fitted with a "telescope pipe" and supporting float to skim water from near the surface, whether the tank be full or not. Thus the densified sludge sinks to the bottom, and the separated liquid is passed to the sewer and so again through the tanks, etc.

Between the two sludge tanks is the sludge pump house, with two sludge pumps of "Tangye's Special Pump" type, each with steam cylinder 16 inches diameter, double-acting piston pump 12 inches diameter, both 24-inch stroke, running up to about thirty-five double strokes per minute: each pump delivering about 200 tons of sludge per hour. These pumps work very satisfactorily, even when dealing with sludge containing 20 or 30 per cent. of solid matter.

From these pumps an 18-inch pipe, 200 yards long, conveys the sludge to the sludge steamer *Salford* at a wharf on the ship canal.

This steamer is 170 feet long, 32 feet beam, about 11 feet draught loaded, and carries 600 tons of sludge in four tanks formed above the light load line so as to discharge through eight 18-inch valves and pipes through the bottom of the ship.

The distance to beyond the north-west lightship off Liverpool is 64 miles, or 128 miles the round trip; and the steamer usually makes four or five trips a week, going with each alternate tide Her fastest round trip was made in about fifteen hours. The cost of disposing of the sludge in this manner is 10*d.* per ton.

The preparation of the precipitants, lime and iron salts, used for the sewage, is provided for in the lime house.

A branch from the L. & N. W. Rly. Co.'s dock line brings the lime trucks directly from the Hoffman Kilns at the Buxton Quarries into the lime house, where the lime is stored for use. A workman fills a wheel-barrow with lime, passes with it up a lift to a raised floor, tips it into one of the lime-slaking pans, and there it is dissolved. The apparatus is in duplicate to provide for repairs, etc.; each set includes two slaking pans with revolving mixers and mixing pan.

When the pan of lime is slaked more water is added, and it flows through a grid where stones, etc., are intercepted, and so into the mixing pan, which is like a mortar mill with two heavy rollers revolving in it, by which any unslaked pellets of lime are crushed, and thence it flows to the mixing chamber already described.

The salts of iron used are a bye-product from a local chemical works, very similar to "copperas." This is easily dissolved in cold water in two mixing pans, but steam pipes are also provided for use if required.

The water used is the tank effluent, raised by small centrifugal pumps. A duplicate couple of steam engines work the machinery.

The chemical laboratory adjoins the lime house; here the resident chemist makes daily analyses of samples taken hourly, and mixed to show each day's average of the crude sewage, the tank effluent, the roughing filter effluent, and the final filtrates from the different bacteria beds. The sewage sludge is also sampled and analysed.

There are also on the works a smiths' and mechanics' shop, ample stores, offices, men's rooms, weighing machines, etc., also the manager's house with a large committee room.

The site of the works is 30¼ acres in extent, and of this about 9¼ acres are still unused, and 2 acres are only used for gardens, etc., the actual sewage works thus occupying only 19¼ acres.

MANCHESTER SEWAGE WORKS (PLATES LXVII.—LXIX., p. 716).

The following information has been supplied by Mr. J. P. Wilkinson, M.Inst C.E., the engineer for the works, and is corrected to Feb., 1908.

The scheme provides for screening and then purifying three volumes of the sewage flow by septic tanks and first contact bacteria beds, at Davyhulme; the carrying from thence to Flixton of the partly purified effluent and its further purification there upon second contact beds, and when necessary, its final treatment by irrigation upon land.

The scheme also provides for the purification of the second three volumes of sewage (as stormwaters) by running it through detritus tanks, and then treating it upon stormwater beds at Davyhulme.

Provision being Made.—The provision which will be made at the completion of the works will be as follows :—

No. 1. At Davyhulme 5 additional tanks which with the existing tanks will make 16, 4 to be detritus tanks, 12 to be septic tanks. The sills of the existing tanks have been raised.

No 2. 46 acres first contact beds in 92 beds at Davyhulme.

No. 3. 27 acres stormwater filter beds at Davyhulme.

No. 4. Conduit to carry first contact effluent from Davyhulme to Flixton.

No. 5. 46 acres second contact bacteria beds at Flixton.

No. 6. 100 acres of irrigation land at Flixton and Carrington.

Capacity of Works.—The average dry-weather flow is taken at 21,000,000 gallons per day. The maximum rate of sewage flow which the works are designed to deal with is 126,000,000, of which the first 63,000,000 are to be treated as sewage and the next 63,000,000 as stormwater. The total flow as delivered and treated throughout the year, including rain, may be taken at an average of between 35,000,000 and 36,000,000 gallons per day.

Detritus and Septic Tanks.—The size in general of each of the old tanks is 300 feet long, 100 feet broad and 6 feet deep, and they originally contained a volume of 1,125,000 gallons each.

Five new tanks have been built, making 16 tanks in all, and the sills of seven of the existing tanks have been raised to bring up their capacity to that of the new tanks, 4 of the old tanks are used as detritus tanks to the stormwater beds and the other 12 are used as septic tanks.

The aggregate capacity of the 12 septic tanks is now 15,820,000 gallons which with the stormwater detritus tanks (which may be used for the night flow) makes a total of 20,320,000 gallons.

The new tanks are built of brickwork in cement mortar faced with blue bricks and coped with stone, except in case of submerged walls which are coped with blue bricks. The floors of the tanks are of cement concrete.

The floors of the tanks are sloped from the outlet to the inlet end, from which the sludge is removed at intervals into a channel beneath the supply channel, from which it gravitates into Shone's ejectors, by which the major part is delivered to the sludge steamer, and thence to the open sea beyond the north-west lightship at Liverpool. During the year 1906-7 the quantity thus sent to sea was 176,314 tons, while 4,861 tons were dealt with by pressing. The "sea" cost for the year was £1,757 10s. 9*d*., and the "works" cost (including pressing £270 6s. 11*d*.) was £2,051 16s. 8*d*.

This works out to 6·47 pence per ton for removal to sea; 2·36 pence per ton for works cost and 13·35 pence per ton for pressing.

For clearance of sludge from tanks, the top water is drawn off by floating arms and pumped back into tanks for re-treatment.

Bacteria Beds.—The bacteria beds at Davyhulme are each a nett half acre in extent and are fed from the septic tanks.

The supply channels vary from 18 to 5 feet wide and fill 2 beds at least in the time allowed for filling. Built under them are the pick-up channels for the effluent from the beds. All channels are made of cement concrete.

There is one point of supply from the channels to the beds in the middle of the long side of each bed.

From the supply channel the septicised sewage runs into a small distributing reservoir semi-circular in shape from which it flows over a weir of semi-circular form into a concentric channel formed in the material of the bed.

The drainage of the beds is effected by radial collecting drains, the main collecting drain and outlet chamber being placed under the distribution reservoir and weir. The drains are formed in the concrete bottom of the beds, having perforated covers and the larger one solid covers cemented to the brickwork. Between these radial drains the floors of the tanks are ridged to facilitate drainage to them. The average depth of the beds is 3 feet 4 inches, and they have a cross fall of 2½ inches.

The floors, walls, etc. of these beds are constructed of concrete. The material with which the beds are filled is screened furnace clinker, the coarsest being used to cover the drains and floors.

Experimental modes of working the beds have been tried, one being that of electrically worked valves, where the period of contact was governed by a timing chamber; the second being a similar method to the above, but the valves were lifted by hydraulic power and the period of contact was under the direct electric control of the operator. Both these methods have, however, been abandoned in favour of sluices operated by hand labour in the usual way.

Stormwater Beds.—The stormwater beds are generally 272 ft. × 160 ft., and about 1 acre each in area, they are 2 feet 6 inches deep and filled with coarse clinker. When full the sewage stands 6 inches above the clinker at which point the bed commences to discharge into a vertical bell-mouth in a discharge chamber. Each bed holds, when full 363,000 gallons, equivalent to a storage of 9,800,000 gallons, and, when so filled, they will discharge at the rate of 2,420,000 gallons per acre per day. The total storage in the stormwater tanks (detritus tanks) and filters, before the filters commence to discharge, equals 14,300,000 gallons, equal to five hours heavy rain. This is exclusive of the bacteria beds. The supply channels are from 10 feet to 4 feet wide, and their gradient is 1 in 1,000. There are two points of supply in the long side f each bed. The distribution and drainage is similar to that for the ntact beds, but the channels and drains are longitudinal and transverse not radial. The enclosing walls of the beds are constructed of t concrete. The outlet valves at the bottom of the beds to empty ter storm are worked by hand.

uent Conduit from Davyhulme to Flixton.—The volume is 63,000,000 gallons per day. The channel is 13 feet

wide and has a gradient of 1 in 5,000. At 2 feet deep it will convey 36,000,000 gallons, and at 3 feet 3 inches deep 73,000,000 gallons with velocities of 155 and 192 feet per minute respectively.

In some places it is constructed as an open channel where it is 13 feet by 4 feet and rectangular in section and is built in concrete. In other places it will be constructed as a closed channel in open cut or tunnel where it will be of similar section, but arched over and built of brickwork.

Secondary Bacteria Beds at Flixton.—These beds will be practically identical with the beds at Davyhulme.

Additional powers have also been obtained for the construction of about 27 acres of secondary beds on an area of land acquired for the purpose in close proximity to the works at Davyhulme: the works at Flixton being held in reserve for future requirements.

Irrigation Land at Flixton and Carrington.—This comprises areas of 64 acres and 36 acres respectively. The supply channel is 13 feet wide, supplying 18-inch radial carriers, composed of glazed socketted earthenware half-pipes. The under drainage is of 3-inch agricultural pipes laid out in herring-bone form at an average depth of 2 feet, to which are connected 9 inches, 12 inches, 15 inches, and 18 inches master-drains of glazed butt jointed pipes.

The total estimated cost, including the old works utilised, the new works now constructed and in prospect, and all lands occupied is about £850,000.

NUNEATON SEWAGE DISPOSAL WORKS (PLATES LXX.—LXXII., p. 720).

These works are a good example of the Double Contact Bed System followed by land treatment of a sewage which is exceptionally difficult to deal with, and the following particulars have been supplied by Mr. J. S. Pickering, M.Inst.C.E., by whom the works were designed.

Plate LXX. is a general plan of the works, Plate LXXI. gives details of the covered silt tanks; Plate LXXII. gives details of the construction of the bacteria beds.

The works were designed to treat a dry-weather flow of half a million gallons per day and stormwater up to three times the dry-weather flow, the excess up to six times the dry-weather flow being dealt with on the old works which are permanently used as stormwater filters.

Upon reaching the site the sewage passes through two revolving wire screens 5 feet in width having $\frac{1}{4}$ inch square meshes. The screen is

driven by a water-wheel operated by the flow of sewage and the apparatus was made by Messrs. John Smith & Co., Carshalton.

Upon leaving the screening chamber the sewage flows through three covered tanks on the Dortmund principle. These tanks are 34 feet deep, 24 feet diameter and have a combined capacity of 150,000 gallons or 30 per cent. of the dry-weather flow.

The heavy mineral matter and other solids in suspension intercepted by these tanks are automatically discharged by the pressure of the sewage in the tanks through a line of 9 inch pipes 450 yards in length to the irrigation area where they are delivered into furrows and deodorised with the soil.

The site of the bacteria beds is about 20 acres in extent and has a natural slope of about 40 feet, thus enabling the tanks to be built in terraces. There are 14 concrete tanks 7 of which are filled with coarse material for first contact and 7 with fine material for secondary beds. Each bed has an area of 1,000 square yards, and the average depth of the filtering material is 4 feet, so that each bed contains 1,333 cubic yards. One third of the cubic capacity of a bed is equal to 75,000 gallons or for the 7 beds 525,000 gallons. With three fillings per day the beds are capable of dealing with 1½ million gallons per day.

A fine screen is fixed at each of the three inlets to each bed to intercept the wool fibre in the sewage

The sewage is distributed over the beds by means of open jointed socketted pipes laid upon the filling material. The material used for filling the coarse beds is broken granite of 2½ inch gauge, the drainage of the beds being effected by means of "U" shaped butt ended tiles laid 4 feet apart.

The filling material for the secondary beds is composed of screened coke dust, the effluent from the coarse beds being applied to the fine beds through channels similar to those on the coarse beds.

These contact beds are not fitted with automatic filling and emptying gear; the valves are all operated by hand and one man is employed in the supervision of all the beds.

The effluent from the secondary beds is discharged upon the land, an area of 60 acres having been acquired for this purpose.

The carriers consist of 18-inch stoneware pipes laid below the ground, the effluent rising in chambers at intervals of 30 to 40 yards for distribution over the land.

The land, which is mostly of a gravelly nature, is underdrained to a depth of 5 feet.

The upper half of the sockets of the main drains are made with a cement joint, the lower portion only being left open. The drains are placed about 40 yards apart.

BIRMINGHAM SEWAGE WORKS (PLATE LXXIII., p. 722).

The Birmingham Sewage Works are carried out by a body known as the Tame and Rea Drainage Board, whose engineer is Mr. J. D. Watson, M.Inst.C.E.

The Board's area comprises several districts in addition to Birmingham itself, and the total quantity of sewage dealt with is 24 million gallons per day in dry weather.

The Board are the owners of a large area of land about 2,800 acres in extent, and the process originally carried on was broad irrigation with chemical precipitation, by means of lime, the sludge being run into trenches and dug into the land.

Since the introduction of the bacterial processes of purification experiments have been carried on by Mr. Watson in various directions, and he is now gradually changing the system to a bacterial process for the ordinary dry-weather flow, and the land is being reserved to deal with fluctuations in quantity during dry weather and three times the dry-weather flow.

The whole of the sewage at present gravitates to the land with the exception of some small areas which are dealt with by subsidiary pumping stations.

The power utilised for this pumping and for other purposes in connection with the works is principally provided by means of an electric power installation in connection with a destructor belonging to the Birmingham Corporation situated at Nechells.

This destructor and power house is a joint undertaking of the Corporation and the Drainage Board, and is situated on land purchased from the Board by the Corporation.

Two batteries of destructors of four cells each on the Heenan & Froude top-feed principle are installed, and these destructors raise steam which is utilised by high-speed Belliss & Morcom engines driving two 115 kw British Thomson-Houston alternating current electric generators. There is also a small continuous current steam set of 15 kw.

This set is used for the purpose of illuminating by means of arc lamps the works at Saltley and to light the station.

The electric current is conveyed from the generating station to the points at which power is required by means of overhead cables carried on creosoted poles set in concrete.

The overhead line consists of hard-drawn copper of special high tensile strength supported throughout its entire length by high tension insulators of the triple-shed type.

Throughout the length of the overhead line a barbed wire is run on

the top of the poles and earthed at frequent intervals for protection against lightning. Where the line crosses roads it is laid underground.

The sewage on arrival at the Saltley Works passes through a series of roughing or detritus tanks, each series being divided into three compartments: the first compartment in which the heavy detritus is deposited is emptied once per week; the liquid from the top of the tank is pumped to the septic tanks and the heavy grit and sludge is lifted by Priestman grabs to sludge trenches where it is buried.

No screening takes place before the sewage enters the tanks, so that the light material includes much which would ordinarily be stopped by a screen. A Stott screen is fixed in front of the suction pipes to the pumps.

The second compartment of the roughing tanks is emptied about once a month, the material being sent forward to the septic tanks, and the third compartments have not been cleaned out for three years.

The septic tanks have a capacity of about 7 million gallons and are uncovered: they are designed with a fall in the bottom, so that the sludge deposit will gravitate to the sludge mains, through which it is pumped about once in four months on to land where it is allowed to dry, and is then dug into the land.

The sludge from these tanks when dug into the land in this way causes no nuisance and dries comparatively rapidly.

After passing through the septic tanks the effluent is taken through tanks constructed on the principle known as the "Birmingham Separator" tank for the purpose of eliminating part of the suspended solids.

These tanks (see Plate LXXIII., p. 722) are somewhat on the principle of the Dortmund tank, and are either circular or square in plan with a conical or pyramidically shaped base.

The sewage is introduced through a central pipe and ascends, discharging over a weir formed in the case of the circular tanks of a trough carried by a girder placed across the centre of the tank; in the square-shaped tanks the weir forms one side of the tank. These tanks are designed to give an upward velocity of 7 feet per hour.

The solids which have been settled are removed from the apex of the cone or pyramid as the case may be by a draw off pipe, which discharges at a level of some 3 or 4 feet below top water level of the tank.

The effluent from the separator tanks is partly dealt with at Saltley and partly at Minworth, at a considerable distance away from the septic tanks, by means of continuous percolating beds.

The general description of these beds is depth 5 to 6 feet, sewage applied by means of fixed jets working with a head of 6 feet, the jets being fixed 12 feet apart.

The material of the beds is granite chippings $1\frac{1}{2}$ inch gauge. The beds are retained by rubble masonry walls and have a false bottom upon a concrete floor, the quantity of sewage applied being at the rate of 150 gallons per square yard per day.

The effluent from the continuous filters contains about 6 or 7 parts per 100,000 of solid matter in suspension.

The effluent is passed through a further series of "Birmingham Separator" tanks in which the solids in suspension are reduced down to from 1·5 to 2 parts per 100,000.

The final effluent is then discharged into the River Tame.

The stormwater is disposed of upon special beds situated at Saltley some 30 acres in extent.

These are constructed with a concrete floor varying from 3 to 6 inches in thickness upon which drain tiles are placed in rows at a distance of about 10 feet from centre to centre, and the space between the tiles is filled up with boulders from 3 inches to 6 inches in diameter.

The medium placed upon these boulders has a total depth of 5 feet consisting of 1 foot of rough breeze 3 inches to 2 inches gauge, 2 feet medium breeze $1\frac{1}{4}$ inches to 1 inch, and 2 feet of fine breeze $\frac{3}{4}$ inch to $\frac{1}{4}$ inch.

The stormwater will all be pumped and is intended to be applied to these beds by means of fixed jet sprinklers at the rate of 3 million gallons per acre of bed per day.

Hanley Sewage Works (Plates LXXIV., LXXV., p. 721).

These works are a good example of the system of purification consisting of detritus tanks and septic tank treatment followed by streaming or percolating filters; the depth of the latter and the size of the filtering medium being unusually small. The main feature of the scheme is the large capacity of the detritus and septic tanks and bacteria beds provided, thus enabling the whole of the stormwater to be treated without special stormwater beds. The engineers were Messrs. Willcox & Raikes, M.M.Inst.C.E., by whose courtesy and that of Mr. Makepeace, their resident engineer, the following particulars have been supplied.

The general arrangement of the works is shown on the plan (Plate LXXIV., Fig. 2, p. 721).

The dry-weather flow is 1,500,000 gallons per day, and the works are designed to treat six times the dry-weather flow or 9,000,000 gallons per day.

The sewage is conveyed to the works in a 4-foot barrel sewer, and is first delivered into the screening chamber, where all floating garbage

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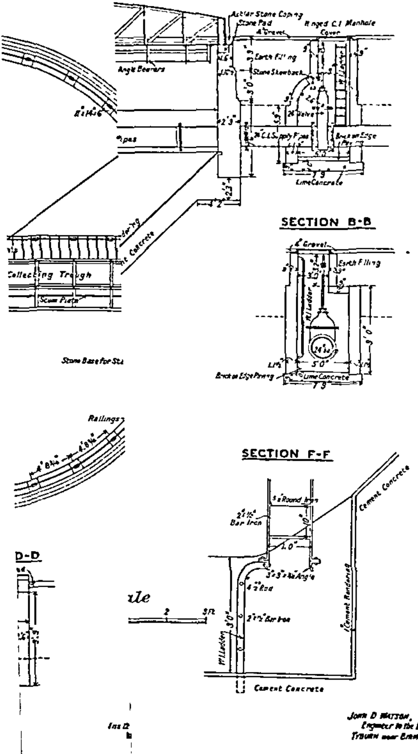


and larger solids are removed, and deposited in a trough provided for that purpose by an arrangement of mechanically-driven rakes which scrape the garbage from the surface of the screens.

On leaving the screening chamber the sewage is gauged by passing over a weir, the rate of discharge being automatically registered by a specially designed recording instrument.

It then enters the detritus tanks, where all the heavier solids are deposited, such as road detritus and other mineral matter, and that proportion of sewage which is pumped to the high level works is delivered into the pump well, any volume in excess of this passing through the old storage tanks to the low level-works by gravitation.

Three detritus tanks are provided for the treatment of the sewage by settlement after leaving the screening chamber, and are so designed that one can nearly always be out of action for cleansing purposes, whilst the other two are in use. Plate LXXIV., Fig. 1, p. 724, gives a general view of the detritus tanks

When the volume of sewage exceeds the 9,000,000 gallons above *referred to it is considered to be so dilute that the Local Government* Board allow it to be discharged into the river after passing through the detritus tanks. A specially designed adjustable bell-mouth overflow is provided for discharging the excess volume as shown in Plate LXXIV., Fig. 3, p. 724.

The total capacity of the three detritus tanks is 342,000 gallons, which is about a quarter of the dry-weather flow.

The capacity of the four high-level septic tanks is 2,050,000 gallons, or one and a third times the dry-weather flow. The low-level septic tanks have a capacity of 2,200,000 gallons and they are reserved for the treatment of stormwater.

Plate LXXIV., Fig. 4, p. 724, gives details of the construction of the septic tanks.

The bacteria beds are constructed on two levels so that the dry-weather flow can be treated by double filtration if this should ever be required.

The total area of the beds is 9 acres, 3¾ acres being arranged on the high-level area, and 5¼ acres on the low-level area, divided into 1-acre plots, as far as possible, each acre in turn being divided into four sections for distribution purposes.

The outer walls of bacteria beds are constructed of 14-inch brickwork with 18-inch reinforcing pillars placed every 12 feet, on a concrete foundation.

The concrete floor is 6 inches thick, with 6-inch half-pipe effluent drains placed 6 feet apart in parallel lines.

The percolation filters are filled with broken saggars, this being a

waste product of the pottery trade and easily obtainable; it forms an excellent material for the purpose and has proved very durable.

The material is arranged as follows:—

9 in.	of broken blue brick	$2\frac{1}{2}$ in. to 2 in.	gauge
1 ft. 0 "	broken saggars	1 " to $\frac{3}{4}$ "	"
2 " 3 "	" "	$\frac{1}{2}$ " to $\frac{1}{4}$ "	"
1 " 0 "	" "	$\frac{1}{4}$ " to $\frac{1}{8}$ "	"
5 ft. 0 in.	Total depth of bed.		

The stormwater from twice up to six times the dry-weather flow is treated in the low-level septic tanks and bacteria beds.

The dry-weather flow is treated once only, and the rate of application to the high-level bacteria beds is about 80 gallons per square yard per day in dry weather, increasing up to 160 gallons per square yard in wet weather. The low-level bacteria beds will deal with four times the dry-weather flow at a rate of 240 gallons per square yard per day.

The filter effluent is collected into a main effluent chamber (where samples can be taken from each quarter acre), and after passing through this, it is conveyed direct to the main effluent carrier, discharging into the River Trent.

As the special type of distributors used on these works constitutes one of their most interesting features, a brief description of their construction may be of interest; but the reasons for using power-driven distributors may first be summarised as follows:—

(1) To obtain absolute control over sewage to be distributed in order to secure any desired period of rest or rate of distribution.

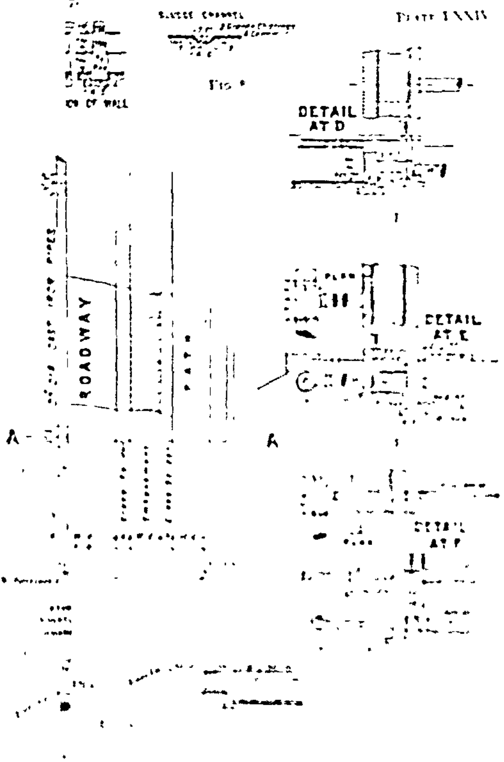
(2) Necessity of discharging sewage close to surface of filter to avoid risk of nuisance to neighbouring houses and park.

(3) Varying rates of sewage flow to be dealt with.

(4) Uniform distribution over the whole area of bacteria beds.

The sewage distributors shown in Plate LXXV., opposite, were manufactured by Messrs. Hartley & Co., of Stoke-upon-Trent, under the special licence of Messrs. Willcox & Raikes, who devised and patented this method of distribution in 1902. During the six years they have been in regular use many improvements have been made by Messrs. Hartley & Co. in the details of their construction. They are arranged in half-acre units, each half-acre bacteria bed being 200 feet long by 100 feet wide, and intersected by an open steel trough about 20 inches square in section. This open trough is supplied by sewage at a fixed level by a 12-inch supply pipe.

The sewage is drawn from the trough and spread over the bacteria beds by two syphons with cocks and distributing pipes, each forming one


DETAIL
AT D
ROADWAY
DETAIL
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DETAIL
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complete arm extending on opposite sides of trough, and the arms travel backwards and forwards along the 200 feet length of the half-acre bacteria bed on chilled cast-iron wheels running on rails, meeting and passing each other when at the middle of each journey.

The distribution of sewage takes place when travelling in one direction only, every alternate journey being an idle one, thus giving the uniform interval of rest necessary for the perfect distribution of sewage.

The distributing pipe is made in section as shown at A (Plate LXXV., Fig. 1, p. 724), and tapers at the outer end to section as shown at B. The outlet of the sewage into the nozzle-pipes from the main pipe is at the top, so that this pipe is never emptied, and by this means the discharge of the sewage commences along the whole length of the pipe almost simultaneously, and all muddy deposit lies in the bottom of the main pipe, and cannot obstruct the outlets to the nozzles. The top of the nozzle-pipe is closed by a plug, and when this is withdrawn the apertures can be readily cleansed. A baffle-plate beneath the nozzle-pipe sprays the sewage upon the bed in a very thin and almost transparent film.

Between the syphon and the main distributing pipe is a stop-cock by which the distribution is stopped or started by means of levers C and D. When one of these levers encounters a stop S, fixed in the end of trough, the cock is closed or opened as desired, and by means of the second lever, which would engage a stop fixed at any desired point along the trough, the distribution can be adjusted so that a portion only of the bed may be used, whilst the other portion is rested. These levers are hinged upwards, so that any one can be instantly put in or out of action.

As both pipes distribute on the same journey, and are idle on the succeeding journey, by increasing the time of the flow journey and decreasing the time of the idle journey it is possible to greatly vary the amount of sewage distributed, and the periods of rest can be adjusted until the most perfect result is obtained.

The distributors are drawn along the rails by wire ropes, and as these would, if independently driven, require considerably increased power during high winds, they are connected together by a balancing rope which passes around grooved pulleys at each end of the bed. When wind adversely presses against one distributor its force is largely counterbalanced by the wind pressure on the other. By this means a small electric motor is sufficient for the work, only 1½ horse power being required to drive each distributor. A tension pulley on slides takes up the slack of the wire rope.

The reversal of the winding drum at the end of each journey is accomplished by a screw which revolves with the drum. Upon this screw is a nut which travels along its axis until, when the required number of revolutions has been made, the nut encounters a pendant

lever and throws over the belt striking-gear, reversing the drum and arms. The nut now travels in the opposite direction until the end of the succeeding journey, when it engages in a second pendant lever and throws over the striking-gear when the reversal of the drum is repeated.

The belt gear is of the usual straight and cross-belt type, with fast and loose pulleys. The intermediate spur gearing shown reduces the speed between the belt pulleys and the rope drum.

In large installations comprising several acres of filters the whole of the distributors for one or more acres can be driven by a single electric motor, and although the motors used at Hanley are capable of developing about 7 horse power per acre of filter, it is found in practice that the electric power actually required does not exceed about 3 horse power per acre.

The distributors have been designed so that they uniformly distribute over the area they cover, doses of from 1 to 2 gallons of sewage per square yard at varying intervals from five to ten minutes, and each distributor on working 24 hours consecutively, at this rate, distributes 500,000 gallons during that period over each bed of a quarter acre area.

Cheltenham Sewage Works

(Plates LXXVI.—LXXVIII., facing pp. 726 and 728).

These works were designed by Mr. J. S. Pickering, M.Inst.C.E., who has supplied the following information and the drawings illustrating the same.

The dry-weather flow is 1,500,000 gallons, and the scheme provides for screening and arresting detritus and then settling or septicising the sewage, precipitating the solids in the septic effluent in circular settling tanks, and the further purification of this effluent on continuous or percolating bacteria beds. The effluent from the filters can, if so desired, be further purified on 133 acres of land by irrigation. The scheme also provides for the purification of stormwaters by irrigation on 25 acres of land and for dealing with the sludge from the septic tanks and circular sedimentation tanks on 2 acres of land.

The detritus tanks are rectangular in shape and covered in, and are three in number. They are placed side by side in continuation of the main sewer, and each is 35 feet long, 10 feet wide, and 6 feet 9 inches deep at the inlet end, and 7 feet 3 inches at the outlet end. To the entrance of each is fitted an inclined screen which is hand-cleaned.

The three tanks have a capacity of 62,000 gallons, equal to a one hour's sewage flow, or slightly over 4 per cent. of the dry-weather flow.

When it is required to clean any one of the three tanks, it can be run off by means of a floating arm fixed at the outlet end of the tanks, the liquid being conveyed by pipes on to the land.

The bottoms of the tanks are made of concrete and the roof of steel joists and concrete. The walls are of brickwork.

The screening house is 43 feet 6 inches long and 10 feet wide. It is built over the inlet end of the detritus tanks and is fitted with an overhead carrier discharging outside the building.

The main sewer is bell-mouthed to practically the width of the three detritus tanks.

From the detritus tanks the sewage flows into a collecting channel, and from thence into a distributing channel from which it flows longitudinally through three closed septic tanks. Each tank is 160 feet 3 inches long, 35 feet 11 inches wide, and is 8 feet deep at the inlet end and 6 feet deep at the outlet end. The three tanks have a capacity of 750,000 gallons, equal to half a day's dry-weather sewage flow.

The sewage flows from the supply channel into short-legged and long-armed tee pipes, of which there is one to each tank.

The long arms of the tee pipes are fixed along the end walls of the tanks and above top water level.

From the bottom of the arms of each tee pipe descend six vertical pipes discharging the sewage into the tank 2 feet 3 inches below top water level.

The first 19 feet of each tank at the inlet end is screened off from the rest of the tank by a brick division wall which extends from above top water level, and through which the sewage passes by means of six vertical U pipes, the orifices of which are 2 feet 3 inches below top water level.

In each sub-chamber formed by the division wall are placed two horizontal helical sludge removers, the floor of the chamber being hollowed to receive them. By these helical removers and the weight of the water in the tank, the sludge can be forced through two outlet pipes (one placed at the centre of each remover) in the bottom of the sub-chamber whilst the tanks are in work.

At the outlet end of each tank the sewage flows by means of six dip pipes extending 18 inches below top water level into a collecting channel, and thence to the circular sedimentation tanks. Each tank can be emptied when so required by means of a floating arm, the liquid being conveyed by pipes on to the irrigation lands.

The main walls and floors of the tanks are made of concrete. The roof is made of concrete and steel joists, and the cross division walls are of brickwork.

The septicised sewage flows from the collecting channels at the end of the settling tanks into a circular distributing pipe placed round the top of each of the circular tanks. From this distributing pipe, by

means of ten vertical dip pipes, it is introduced into the bottom of the circular sedimentation tanks. These tanks are three in number, one to each septic tank. They are circular in shape, 25 feet in diameter, and average 15 feet 3 inches in depth measured from top water level.

The capacity of the three tanks is 140,625 gallons, or $2\frac{1}{4}$ hour's dry-weather sewage flow. The liquid flowing upwards through the tanks is drawn out of them by ten dip pipes projecting downwards to 1 foot 9 inches below the surface of the liquid in each tank. The dip pipes discharge into an annular collecting channel placed round each tank, through which it runs into a rectangular conveying channel.

The bottom of each tank is fitted with a horizontal helical mud remover, the bottom of the tank being dished to receive it, a sludge pipe being fixed at the centre of the remover. By these helical removers and the weight of water in the tank, the solids which settle at the bottom of the tanks can be forced out of them through the outlet pipes whilst the tanks are in work.

The walls of the tanks are built of brickwork, the floors of concrete, and the roof of concrete and steel joists.

The effluent from the septic tanks after passing through the circular sedimentation tanks flows into four dosing chambers, preceding eight circular trickling or percolating filters.

These filters are built in batteries of four, and the levels are such, that if it is thought fit, the effluent from the higher battery can be discharged on to the lower. Each filter is 113 feet diameter and 6 feet deep, and has a cubical content of 2,228 cubic yards, giving for the eight beds a capacity of (at 168 gallons per cubic yard, L. G. B.'s rule) 3,000,000 gallons per 24 hours, equal to twice the dry-weather sewage flow. The average rate of flow of ordinary dry weather is 133 gallons per square yard per day.

From the trickling filters the effluent is discharged on to 133 acres of land, where it can be further treated by irrigation.

The stormwaters are discharged directly on to 25 acres of land, where they are also treated by irrigation.

The areas of land which are allocated to the various portions of the treatment of the sewage are as follows:—

Area to be irrigated by upper battery of filters	75	acres.
,, ,, lower battery of filters	58	,,
,, ,, stormwaters ...	25	,,
	158	,,
For sludge trenches	2	,,
Total	160	,,

The Rothwell Sewage Disposal Works
(Plates LXXIX., LXXX., p. 730).

These works are designed to deal with a dry-weather flow of 100,000 gallons of domestic sewage from a population of 5,000 persons upon the continuous filtration system, and are of interest as being an example of the application of fresh sewage to percolating filters on what is known as the "Leeds Bed" system.

The sewage is delivered at the works through a 24-inch sewer, to a detritus tank and screening chamber, and thence passes to a reservoir provided with two compartments for the storage of the night flow.

The sewage is pumped from the reservoir by means of centrifugal pumps driven by gas engines consuming producer gas.

The delivery pipe from the pumps ascends to the first floor of the engine house to a screening chamber containing a revolving screen with a perforated plate with openings $\frac{1}{16}$ inch in diameter. This screen is described on p. 592.

After passing through the screen the liquid is carried to two circular bacteria beds which are constructed as shown upon the plans with walls of honeycombed brickwork in which are two wrought iron bands. The filtering material is 10 feet deep and is of unusually large size; the greater part of it is broken clinker bricks, the pieces being from 3 inches to 4 inches in diameter, and the top layer is of rounded gravel pebbles 2 inches in diameter.

The liquid is applied to these beds at the rate of 6 gallons per square yard per hour by ordinary circular revolving distributors by Candy.

The effluent from the bacteria beds is well oxidised and contains a very large proportion of solid matter in suspension. In order to arrest this the effluent is passed through sand filters of the ordinary water-works construction. They contain a layer of gravel 6 inches thick carrying a bed of sand 6 inches thick. A large area of these sand filters is provided so that the beds can be rested long enough to dry the sludge. There is no difficulty in doing this and the thin film of sludge left on the sand can be skimmed off with shovels and is found to be easily handled and quite free from smell.

The effluent from the sand filters is discharged into a small tributary of the River Aire.

A stormwater filter is provided of similar construction to the previously described sand filters except that the filtering material is 2 feet in depth instead of 12 inches.

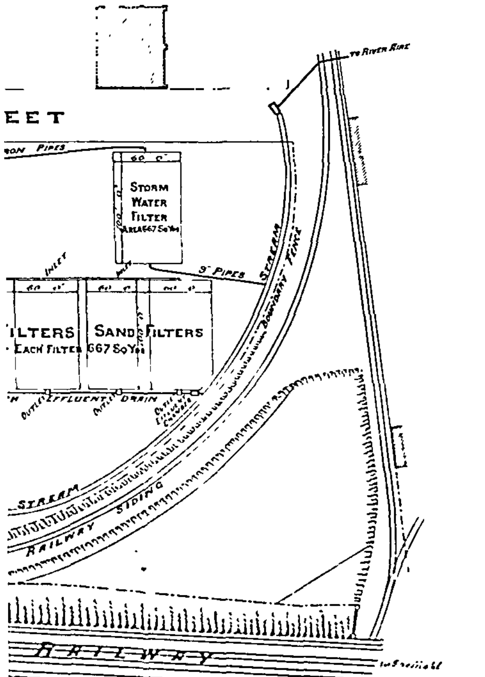
Two small sludge beds have been constructed to deal with the heavier solids which are deposited in the detritus tank, this matter being lifted by a small hand chain-pump.

It was intended that the whole of the solids brought down by the sewage should be pumped on to the bacteria beds, but it was found that a small deposit took place in the reservoir at night when no pumping was going on. It has therefore been found necessary occasionally to pump this sludge out with the ordinary sewage pumps, and this is dealt with in the sludge beds through an outlet made for the purpose on the delivery pipe to the stormwater filter.

During the day-time the fresh sewage is pumped direct to the bacteria beds with all the solids in suspension still in it.

PURIFICATION WORKS.

LAN.



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CHAPTER XX.

ROYAL COMMISSION ON SEWAGE DISPOSAL AND LOCAL GOVERNMENT BOARD'S INQUIRIES.

A Royal Commission was appointed in 1898 to deal with the question of Sewage Disposal. This body issued an Interim Report in July, 1901.

Interim Report.

This Report was published primarily to deal with the question of the requirements of the Local Government Board with regard to land as a final treatment to all systems of sewage purification.

Since 1884, the practice of the Local Government Board had been to require, save in exceptional cases, that any scheme of sewage disposal for which money was to be borrowed, should provide for the application of the sewage or effluent to an adequate area of suitable land before its discharge into a stream.

In many cases, especially in the manufacturing districts of Yorkshire and Lancashire, the land available for sewage purification is either unsuitable in quality, inadequate in area, or can be obtained only at a prohibitive cost, and great difficulties presented themselves to local authorities seeking to purify their sewage for the above-named reasons.

The Commission, after hearing evidence, examining existing sewage works, and carrying on experiments of their own under skilled officials appointed for the purpose, came to the conclusion that peat and stiff . lands are generally unsuitable for the purification of sewage; that for this purpose is always attended with difficulty, and that the top soil is shallow, say six inches or less in depth, the area lands which would be required for efficient purification in certain cases, be so great as to render land treatment ble.

conclusion of the Commission was that after carefully the whole of the evidence, together with the results of their they were satisfied that it was practicable to produce by alone, either from sewage or certain mixtures of

sewage and trade refuse, such, for instance, as are met with at Leeds and Manchester, effluents which will not putrefy, which would be classed as *good according to ordinary chemical standards, and which* might be discharged into a stream without fear of creating a nuisance.

The Commission expressed the opinion that there were cases in which the Local Government Board would be justified in modifying, under proper safeguards, their rule as regards the application of sewage to land, but the Commission were not able to give general rules as to what *those safeguards should be, but suggested that each case should be* considered on its own merits.

The direct result of this conclusion was that the Local Government Board did relax their rules, and numerous schemes have since been sanctioned in which land treatment forms no part.

The Interim Report embraces a third conclusion which deals with the necessity of protecting all rivers, and expresses the opinion that a separate Commission or new department of the Local Government Board should be created, dealing with matters relating to rivers and their purification, with power to take action in cases where local authorities failed to do so.

Second Report.

The Commission issued a Second Report in July, 1902, which consisted entirely of reports by the experts appointed by the Commission upon various features of the problem placed before the Commission.

Third Report.

The Commission issued a Third Report in March, 1903, dealing with the question of trade effluents and a new central authority, from which it appears that the Commission arrived at the conclusion that sewage containing trade effluents is generally more difficult to purify than ordinary sewage, and that the following are the chief causes of the difficulty.

(1.) The trade effluents may be turned into the sewer at irregular intervals, so that the composition of the sewage as it arrives at the sewage works varies considerably throughout the day.

(2.) The trade effluents may contain large quantities of solids in suspension which tend to choke the purification plant.

(3.) The trade effluents may be very acid or very alkaline, or otherwise chemically injurious.

The evidence brought before the Commission shows that wherever practicable the manufacturer should adopt means of removing the bulk of the solids in suspension from his effluent, for neutralising it and for

delivering it into the sewer in a fairly uniform manner, and in most cases the Commissioners were of opinion that the cost to the manufacturer of adopting these preliminary measures would be less than the additional cost which would be thrown on the local authority if the measures were not adopted.

The Commission concluded that the purification of trade effluents by the local authority is in the majority of cases practicable; purification by the manufacturer is in some cases difficult, if not impracticable; while purification by the manufacturer would generally be more costly than purification by the local authority, also that the local authorities as well as the manufacturers are of opinion that there should be laid on the local authority a distinct obligation to receive trade effluents.

The Commissioners therefore recommended that the law should be altered so as to make it the duty of the local authority to provide such sewers as are necessary to carry trade effluents as well as domestic sewage, and that the manufacturer should be given the right, subject to the observation of certain safeguards, to discharge trade effluents into the sewers of the local authority.

Without providing by direct enactment what these safeguards should be, the Commissioners recommended that in each district the local authority should frame regulations which should be subject to confirmation by a central authority, and that in most cases these regulations should provide definite standards for the different manufacturers as regards preliminary treatment, with power to vary or dispense with such standards where necessary.

In many cases a part or the whole of the water which the manufacturer uses in his business is obtained from a stream, and must therefore be returned to that stream.

The Commissioners did not propose that the manufacturer should by statute be relieved of that liability. If he be able to relieve himself of the obligation he might discharge his effluent into the sewer, but the local authority should be expressly exempted from any liability for the infringement of riparian rights by the discharge into the sewers of water obtained from any stream.

The question of a special charge beyond the ordinary rates paid for sanitary purposes being made upon the manufacturers who discharge their trade effluents into sewers is one of great difficulty, and the Commissioners found that however much may be said in support of such a contention, they could not disregard the following considerations:—

(a) Under the existing law the local authority are not empowered to make a special charge.

(b) The evidence shows that, though it would be practicable were such a charge made, to ascertain what that charge should be, yet it would

involve a very large amount of labour to settle the charge in respect of each manufactory.

(c) In the interests of the community it is desirable that most trade effluents should, subject to certain safeguards, enter the sewers and be purified by the local authority.

(d) In the interests of manufacturers no new restrictions which are not essential should be imposed.

(e) A distinction ought to be made between the cases where the manufacturer complies with the regulations as to preliminary treatment, and the cases where he does not; and many important witnesses representing local authorities have strongly expressed the view that no special charge should be made in the former class of cases.

Having regard to these considerations the Commissioners were of opinion that generally no special charge should be made on the manufacturer in those cases in which the regulations as to preliminary treatment are complied with. But where the manufacturer is unable to comply with these regulations they considered that the local authority should be empowered to make a special charge.

Power should also be granted to make a special charge, even when *preliminary treatment is adopted, where there are exceptional circumstances* as regards volume, quality or otherwise.

They recommended that the actual amount of the charges should be fixed by agreement between the manufacturer and the local authority.

In default of agreement the amount should be settled by a superior authority in the manner hereinafter explained.

In those cases in which a manufacturer is precluded from discharging his effluent into the sewer by reason of the fact that the water which he uses is obtained from a stream, and must therefore be returned to the stream, the duty of purification will still rest with him.

But the Commissioners did not consider that this will be a serious grievance, as he obtains his water without charge, and this advantage may be set against the cost of purification.

Moreover, it would be open to him to acquire the right to use the sewer by getting his water from some other source or by obtaining the necessary consent of riparian owners below him on the stream.

In dealing with the cases of manufacturers who have obtained by prescription a right to discharge their trade effluents into the sewers of a local authority, the Commissioners considered that all manufacturers should be placed upon the same footing, and that the regulations for preliminary treatment and special charges upon the manufacturers should apply equally to those manufacturers whose effluents now are discharged into the sewers and to the manufacturer who is only proposing to obtain connection.

The Commissioners urge the necessity for the creation of a central authority to deal with the differences between the local authorities and manufacturers, particularly with questions which may arise under the following heads :—

(1.) The refusal of a local authority to allow a particular trade effluent to enter their sewers.

(2.) The refusal of a local authority to construct or enlarge sewers for the purpose of a particular manufactory.

(3.) The question of varying general regulations as to preliminary treatment by the manufacturer.

(4.) The amount of the special charge to be imposed on the manufacturer.

(5.) The removal of sludge.

They considered the Law Courts unsuitable tribunals for the settlement of questions of this kind, and recommended that a properly equipped central authority should be established with a permanent staff of experts, that the authority should be clothed with the necessary powers to conduct inquiries, call witnesses, enter premises to take samples of the trade effluent, and generally to do such acts as are necessary to properly perform their duties.

That at any inquiries which may be held, neither counsel nor expert witnesses should be heard except with the special permission of the central authority ; that the central authority should be a new department under the Local Government Board rather than an entirely separate department.

They further recommended that Rivers Boards should be established throughout the country and that such Boards should act as courts of first instance in dealing with disputes, except those arising from :—

(a) The refusal of a local authority to allow a particular trade effluent to enter their sewers.

(b) The refusal of a local authority to construct or enlarge sewers for the purpose of a particular manufactory.

These matters to be dealt with by the central authority alone.

Local Acts of Parliament.

These recommendations have not up to the present been acted upon ; but the subject of dealing with trade refuse has been settled in certain of the manufacturing towns by local Acts of Parliament, and the following extract from the Halifax Corporation Act, 1905, is an example of clauses introduced into such Acts dealing with the question :—

Disposal of Trade Refuse.

Halifax Corporation Act, 1905.—5. The Corporation shall for the purposes of this Part of this Act have the like powers and duties with

Powers of Public Health Act to apply

respect to construction and maintenance of sewers and drains and the removal treatment and disposal of trade refuse and the purchase and taking of lands by agreement or otherwise than by agreement and the expenditure of money and execution of works as they have for the construction and maintenance of sewers and the removal and disposal of sewage under the *Public Health Act 1875* and all the provisions of that Act and of any Act incorporated therewith so far as applicable and not inconsistent with this Part of this Act shall apply accordingly.

Traders may discharge trade refuse *into sewers.*

6.—(1) Subject to the provisions of this Part of this Act any trader may require the Corporation to receive and dispose of the trade refuse produced from his trade premises and shall be entitled to discharge or continue to discharge such trade refuse through any drains communicating with the sewers and for such purpose shall be entitled to enlarge or alter such drains or construct new drains and cause the same to empty into the sewers of the Corporation subject to the provisions of section 21 of the Public Health Act 1875.

Notice of intention to discharge

(2) Any trader requiring the Corporation to receive and dispose of trade refuse as aforesaid or intending to discharge trade refuse into any sewer by any drain not used for such purpose at the date of the passing of this Act or proposing to enlarge or alter any drain used for the purpose of discharging trade refuse into any sewer shall at least one month before so requiring or commencing to so discharge enlarge or alter serve the Corporation with notice of his requirement or intention or proposal as aforesaid and stating the branch of industry or trade carried on on the trade premises affected and the name and postal address of the owner and the occupier respectively of such premises and every part thereof.

(3) The provisions of this section shall not come into force until the expiration of twelve months after the passing of this Act or until the regulations to be made as hereinafter provided shall come into operation whichever shall first happen Provided also that in the meantime the existing rights of the Corporation and the traders respectively shall remain unaffected.

Production of Plans, etc.

7. *The owner and occupier of any lands on in through or under* which any drain pipe channel or outlet is situate by means whereof any trade refuse flows or is or may be discharged into any sewer within the borough shall upon application in writing by the Corporation produce for inspection by the Corporation or their officers or agents and the Corporation shall upon application *in writing by any such owner or* occupier as aforesaid produce for inspection by him or his agents all such plans of such drain pipe channel or outlet or sewer as aforesaid as he or they respectively possess and if required shall furnish to the Corporation or to such owner or occupier as the case may be at reasonable charges

copies of all such plans and such information thereon as he or they respectively is or are able to afford and in case of default shall be liable for every such offence to a penalty not exceeding five pounds and to a further penalty not exceeding forty shillings for every day during which such default shall continue.

Power to make separate or combined systems of schemes.

8. The Corporation may construct or provide any separate sewers or other work for receiving and disposing of any trade refuse as aforesaid or by means of a combined scheme or schemes with all necessary sewers and works may receive and dispose of the trade refuse from two or more manufacturing or trading premises as aforesaid apart or separately from the general sewerage system or disposal works of the Corporation.

Power to Corporation to combine with other authorities.

9. The Corporation may combine with the local authority for any other district for the purpose of the exercise and performance of the powers and duties of the Corporation under this Part of this Act and may enter into and carry into effect any agreements for such purpose.

Disposal of sludge, etc.

10. The Corporation may at the request and cost of any trader or other person for the time being interested in any trade premises remove and dispose of any sludge deposit or other substance which may have been produced in the course of the treatment of trade refuse upon or in connection with such trade premises.

Corporation may make general regulations.

11.—(1) The Corporation may subject as hereinafter in this section mentioned make general regulations which shall be conformed to by traders who now or shall hereafter discharge trade refuse into the sewers under this Part of this Act Such general regulations may include reasonable charges by the Corporation for the removal and disposal of trade refuse where there shall be no preliminary treatment thereof or where there shall be exceptional circumstances as regards volume quality or otherwise and such general regulations and charges in the first instance shall be settled by agreement between the Corporation and the traders representatives duly appointed at a general meeting of traders held for that purpose as hereinafter provided or failing agreement shall be settled in manner provided by the section of this Act the marginal note whereof is "Reference of questions in dispute."

Meeting of traders.

(2) A meeting of the traders for the purpose of this section shall be summoned by not less than seven clear days' notice by advertisement in one or more newspapers circulating in the borough and such meeting shall be convened by Clement Holdsworth of Shaw Lodge Halifax worsted manufacturer or the chairman for the time being of the Halifax Traders' Committee and be held within two months from the passing of this Act or failing this shall be convened by the mayor of the borough Such meeting shall act by a majority of the traders present.

half-yearly instalments extending over such period as shall be allowed to the Corporation for repayment of loans for sewage works not exceeding twenty years and such instalments shall be recoverable against the owner or occupier for the time being of the trade premises and until repayment shall be a charge on such trade premises.

Apportionment of amount payable for works.

(2) If the occupier of any trade premises shall not be the owner thereof or if more than one person shall be interested therein either as owner or occupier or if the said works relate to more than one trade premises the amount payable shall be apportioned between the several interests or trade premises (as the case may be) affected in such manner and upon such terms as may be agreed between the parties interested or failing agreement in manner provided by the section of this Act the marginal note whereof is "Reference of questions in dispute" and in such case the charge mentioned in subsection (1) of this section shall be limited to the several interests or trade premises (as the case may be) respectively affected.

Saving of right to accelerate instalment payments.

(3) Nothing in this section shall prevent any trader or person interested as aforesaid in any such trade premises from at any time or times paying off any balance for the time being owing of any advance or any apportioned advance with interest thereon or on any portion thereof to the date of payment in excess of any instalments for the time being payable in respect thereof and on repayment of any advance or apportioned advance (as the case may be) with interest thereon the charge on the interest or interests or trade premises (as the case may be) respectively affected thereby shall be deemed to be void and at an end.

Expenditure to be expenses within interpretation of net annual value.

(4) In the assessment of the annual value of trade premises for rating purposes any expenditure under this Part of this Act required to be incurred by the trader to enable such trade premises to fulfil the requirements of any regulations for the time being in force with respect to such premises shall be deemed to be included in the words "other expenses" in the interpretation of the words "net annual value."

Corporation to bear portion of costs for domestic sewage.

(5) If any works within this section or any part of such works shall be intended or at any time utilised for domestic sewage at the request or with the concurrence of the Corporation and the trader or traders interested therein such part of the cost of such works as shall fairly represent the value of such user shall be paid or allowed by the Corporation. The amount of such payment or allowance as the case may be as well as any apportionment as between traders interested shall failing agreement be settled in manner provided by the section of this Act the marginal note whereof is "Reference of questions in dispute."

(6) The provisions of this section shall apply notwithstanding the terms of any contract of tenancy subsisting between the parties and which has been entered into whether before or after the date of the passing of this Act. As to existing tenancies.

15. Any trader who shall wilfully discharge any trade refuse into any sewer except in accordance with the provisions of this Part of this Act or of any regulations for the time being in force thereunder or who shall otherwise infringe such regulations shall be liable on the application of the Corporation to a penalty not exceeding twenty pounds and to a daily penalty not exceeding five pounds. Penalty for wilful default.

16. Nothing in this Part of this Act shall affect any written agreement between the Corporation and any trader whereby for valuable consideration any trade refuse produced at or proceeding from the trade premises of such trader is admitted into the sewers but any such agreement made after the date of the passing of this Act shall be filed with any regulations affecting trade premises in the same branch of industry or trade and be subject to the like rights of inspection as such regulations. Saving of agreements.

17. Nothing in this Part of this Act shall prejudice or affect the rights of riparian owners or justify any infringement of such rights Provided that if pursuant to this Part of this Act any trade refuse is received into the public sewers in contravention of any such riparian rights the remedy for such contravention shall be against the trader and not against the Corporation. Reservation of rights of riparian owners.

Similar clauses have been inserted in the Heckmondwike Improvement Act, 1905, and the Huddersfield Corporation Act, 1906.

The following are the regulations agreed upon between the Halifax Corporation and the Traders.

General Regulations Pursuant to Section 11 of the Halifax Corporation Act, 1905.

1. Trade refuse shall be discharged into the sewer at a uniform and regular rate of flow during working hours so far as reasonably practicable and with due regard to space and requirements of the business for the time being carried on on the trade premises affected.

2.—(a) The Corporation may construct and maintain at their cost at or near the outlet of the drain into the sewer an examination shaft and apparatus so designed as to enable the Corporation or their officers to obtain from time to time samples of the trade refuse discharged into the sewer.

(b) Any sample obtained by the Corporation for the purposes of this

Act shall be taken in two bottles of similar size and construction and shall forthwith before removal from the premises be securely sealed up and signed and marked with the date and time of and place where taken by the person taking the same, and one bottle shall be left by such person with the trader or his representative for the time being in charge of the trade premises affected.

3. Any works shall be constructed and carried out subject to the general regulations and the Acts of Parliament (public or local) for the time being in force in the borough of Halifax in relation to the construction of drains and the connection thereof with the sewers.

4. All statutory powers vested in the Corporation for the inspection of drains shall apply to any drain to which this Act applies.

5.—(a) Any trader now or hereafter adopting preliminary treatment of trade refuse shall provide maintain and use on the space to be provided for the purpose all plant and apparatus necessary and proper so far as reasonably practicable within the intent and meaning of Section 11, Sub-section (3) of the said Act to effect a preliminary treatment of the trade refuse produced by him at the trade premises affected before discharging the same into the sewer or into any drain communicating therewith.

(b) Any preliminary treatment works fulfilling the requirements of part (a) of this clause maintained and used at the date when these regulations shall come into force shall for all purposes be deemed to have been provided to fulfil the requirements of these regulations.

6.—(a) Wherever the Corporation shall be entitled under the said Act to make any charge for the removal and disposal of trade refuse they may charge the trader in accordance with the Table set forth in the Schedule hereto.

(b) In case of any industry not coming under one of the several sub-divisions of the classes for the time being mentioned in the said Table being hereafter carried on by any trader such industry shall be entered under one of the said classes as a sub-division thereof or shall be entered as an additional class of industry and a charge fixed thereunder as may be agreed between the Corporation and the trader.

(c) The quantity of trade refuse to which any charge shall apply shall, subject to Clause 7, be agreed between the Corporation and the trader.

7. If any dispute or difference shall at any time or times hereafter arise between the Corporation and any trader as to the construction or operation of these regulations or in case the parties shall not agree upon any matter which is the subject of agreement hereunder either party may refer the same to arbitration in accordance with Section 13 of the above-mentioned Act.

8. In these regulations words and expressions to which meanings are assigned in the Public Health Acts and Rivers Pollution Prevention Act, 1876, and the above-named Act have the same respective meanings unless there be something in the subject or context repugnant to such constructions.

Dated this day of 1907.

For Corporation.

Town Clerk.

For Traders' Representatives.

Chairman.

SCHEDULE.

TABLE OF CHARGES FOR REMOVAL AND DISPOSAL OF TRADE REFUSE. (REGULATION 6)

Class.	Trade	Charge per million gallons		
		£	s	d
1	Wool combing Wool washing Yarn scouring Silk washing	10	0	0
2	Curriers	8	0	0
3	Dripping makers Waste bleaching Tripe dressing Chemical works	5		
4	Dyeing Textile printing Brewing Bottle washing Mineral water works Soap making Gas working Stone sawing Card clothing manufacturing Grain washing Wire works	3	0	0

FOURTH REPORT OF THE ROYAL COMMISSION.

In December, 1903, a Fourth Report was issued by the Royal Commission on Sewage Disposal, dealing with the pollution of tidal waters, with special reference to contamination of shell-fish.

The Commissioners stated that they were satisfied that injuries to health and to fisheries may be caused by the discharge of unpurified sewage into tidal waters and that some alteration of the law is required.

A change in the law is especially needed in the case of tidal waters in which shell-fish are laid, but there are other evils besides the contamination of shell-fish to be guarded against, amongst which may be mentioned the following:—

(1) Offensive putrefaction.
(2) Reduction of oxygen to such an extent as to render the water incapable of supporting fish life.
(3) Destruction of the fish by poisons or the clogging of their gills by suspended matters.
(4) Washing up of fæcal matter on the shore.
(5) Formation of sludge banks.
(6) Objectionable contamination of bathing places.

The Commission after careful consideration concluded that shell-fish which have become contaminated by sewage may convey enteric fever and other illness to human beings if eaten raw or in an imperfectly cooked condition, and they were satisfied that a considerable number of cases of enteric fever and other illnesses had emanated from this source, and that the evil is sufficiently grave to demand a remedy.

The remedies suggested may be divided into three general classes:—

(1) Purification of the sewage before its discharge into tidal waters.
(2) Seizure and destruction of unwholesome shell-fish exposed for sale.
(3) The setting up of a competent authority to deal with all tidal waters, with power to control foreshores, to close dangerous beds, pits, ponds and layings, and in certain circumstances to *require treatment of sewage.*

With regard to the first of these the Commission point out that the effluents from sewage farms, as well as from artificial purification processes, usually contain large numbers of bacteria, many of which appear to be of intestinal derivation, and that sewage effluents must be regarded as potentially dangerous if allowed to discharge into the immediate neighbourhood of shell-fish layings.

In such cases they consider that the sewage outfall must be removed or the layings closed.

In other cases, where the layings are at a considerable distance from the outfall and the sewage would be largely diluted before reaching them, treatment of the sewage might be of value in diminishing the risk.

The proposal that the sale of contaminated shell-fish might be

prevented by proceedings under section 116 *et seq.* of the Public Health Act, 1875, was considered by the Commission to be practically useless, as there is nothing in their appearance to distinguish shell-fish which had been exposed to sewage contamination from those which had not been so exposed, and in the present state of knowledge it would not be practicable to make the distinction by the aid of a bacteriological examination as a routine measure.

After carefully considering the question the Commission concluded that the only way in which this evil can be effectually dealt with is by placing tidal waters under the jurisdiction of some competent authority, and confer upon that authority power to prevent the taking of shell-fish for human consumption from any position in which they are liable to risk of dangerous contamination, and to enforce regulations as regards pollution both to tidal waters and also to ponds, beds and layings, in which shell-fish are fattened or stored; and the Commission were of opinion that these duties could be best carried out by the River Boards recommended in their Third Report, subject to an appeal to the central authority therein suggested.

These suggestions have not up to the present been acted upon.

The Fourth Report was accompanied by a volume containing notes on the evidence as to pollution of fishing grounds by sewage upon which the recommendations of the Commission were founded.

Along with this Report was issued a third volume containing Reports by Dr. A. C. Houston on Bacteriological Investigations in connection with the Shell-fish Inquiry, and also a fourth volume in parts containing reports to the Commission by Dr. G. McGowan, Dr. A. C. Houston and Mr. G. B. Kershaw, on the Chemical, Bacteriological, Engineering and Practical Observations on certain Sewage Farms which they had had under observation.

These Reports contained in Vol. IV. are of a very detailed character, and contain information which has been compiled in a more systematic fashion than has ever been attempted before. Some of this information has been included in the pages of the present work dealing with land treatment of sewage.

The chemical standards suggested by various authorities were discussed, but no new standard was proposed, although certain indications were given of the direction in which such a standard might be framed.

On the other hand, when dealing with the bacteriological side of the question, Dr. Houston was obliged to set up provisional standards as a basis of comparison, and these standards will be found on p. 586, under the heading of Standards.

When comparing the results obtained, it is pointed out that although

it was not to be expected that the chemical and bacteriological results would always show a direct parallelism or that the inferences to be deduced from the separate results should in all cases be in close agreement, nevertheless these two aspects of the problem of sewage purification are not mutually antagonistic, but are to some extent related to and in sympathy with each other.

The view is also expressed that in the present state of knowledge the association of biology with chemistry is to be recommended in connection with the discharge of effluents into streams, whether these be drinking or non-drinking water streams. In the former case, the bacteriological results are considered of more importance than the chemical; but in the latter the converse holds good, *i.e.*, the chemical results are of first importance.

The general conclusions drawn by the experts from their observations are numerous, and amongst the most important are that from the bacteriological point of view the effluents from land processes of sewage treatment are not in a proper condition for discharging into drinking water streams;

That the effluents from land possess a bacteriological flora characteristic of sewage but that the microbes characteristic of soil are relatively absent;

That treatment on land does not seem to modify to any material extent the biological character of sewage, but the number of bacteria are reduced to a marked extent;

Samples of storm-water examined were almost invariably found to be most impure both chemically and biologically.

That with proper management there is no reason to doubt that land can purify sewage for a practically indefinite period.

The general summary with regard to the capacity of various kinds of land to deal with sewage is as follows:—

In the first place, the best kind of soil for filtration purposes (*e.g.*, light sandy loam overlying gravel and sand) can certainly purify to a remarkable extent, at the rate of 23,000 gallons of a strong mixed sewage per acre per 24 hours (*a*) at a given time; and over 10,000 gallons per acre per 24 hours (*b*) on the year's working of the total irrigable area. Further, under (*a*) and (*b*) sets of conditions, over 100,000 and over 30,000 gallons respectively of a rather weak sewage can be purified to a fair although not to an altogether satisfactory extent.

Secondly, with soil less well suited for filtration purposes (*e.g.*, sand and partially peaty soil lying upon sand and gravel), from about 25,000 to 46,000 gallons of sewage per acre per 24 hours (*a*) at a given time; and from about 8,000 to 23,000 gallons per acre per 24 hours (*b*) on

the year's working of the total irrigable area, can be treated so as to yield effluents fairly good, but, on the whole, not quite satisfactory.

Thirdly, with soils passing from gravelly loam to heavy loam or clay all being worked as combined surface irrigation and filtration farms, from about 12,000 to 57,000 gallons of sewage per acre per 24 hours (*a*) at a given time; and from about 4,000 to 9,000 gallons per acre per 24 hours (*b*) on the year's working of the total irrigable area can be treated so as to yield effluents moderately good, but still not altogether satisfactory.

The experts conclude in the following terms:—

To summarise all our results within the limits of a few sentences is impossible, but we may say in conclusion, and speaking in general terms, that we doubt whether even the most suitable kind of soil worked as a filtration farm should be called upon to treat more than 30,000 to 60,000 gallons per acre per 24 hours at a given time (750 to 1,500 persons per acre); or more than 10,000 to 20,000 gallons per acre per 24 hours, calculated on the total irrigable area (250 to 500 persons per acre). Further, that soil not well suited for purification purposes, worked as a surface irrigation or as a combined surface irrigation and filtration farm, should not be called upon to treat more than 5,000 to 10,000 gallons per acre per 24 hours at a given time (125 to 250 persons per acre); or more than 1,000 to 2,000 gallons per acre per 24 hours, calculated on the total irrigable area (25 to 50 persons per acre). It is doubtful if the very worst kinds of soil are capable of dealing quite satisfactorily even with this relatively small volume of sewage. The population per acre is calculated on 40 gallons of sewage per head per day. It is here assumed that the sewage is of medium strength, and is mechanically settled before going on to the land.

Fifth Report.

The Fifth Report was issued in September, 1908, whilst the present edition was in the press, and it has therefore been possible to include here a *resumé* of the principal recommendations put forward.

The Report itself is a comprehensive treatise dealing chiefly with artificial methods of purification, and, as a work of reference, should be in the hands of all engineers dealing with sewage purification problems.

The Commissioners, at the commencement of their Report, express the general conclusion that it is practicable to purify the sewage of towns to any degree required, either by land treatment or by artificial filters, and that there is no essential difference between the two processes, for in each case the purification, so far as it is not mechanical,

Using materials which are not liable to disintegrate;

Using for the body of the filter material of even size, and in the form of cubes or spheres rather than flakes;

Allowing thorough and efficient drainage;

Not overworking the bed;

Giving periodical rests;

Filling and emptying the bed in such a way as not to disturb the material.

The access of suspended matter to a contact bed is, in most cases, the chief cause of loss of capacity, and no doubt the rate of loss can be greatly lessened by carefully eliminating the suspended solids from the sewage before filtration.

Particulars of the cost of washing the filtering medium in contact beds varies according to local circumstances, but particulars are given of the cost in several towns and it appears that where machinery is employed for the purpose the cost, including making up the loss of material but excluding the cost of machinery and its maintenance, varies from 1*s.* to 2*s.* 2½*d.* per cub. yard, with an average of 1*s.* 6¾*d.*, and that material washed by hand varies from 1*s.* 2½*d.* to 2*s.* 6¾*d.* per cub. yard, with an average of 2*s.*

The average length of time which the material can be used without washing is four years for primary beds and ten years for secondary beds.

The filtering material used for contact beds is principally clinker and coke, but other materials have been used, apparently with equally good results.

There is some evidence of better effluents being obtained from coke than from clinker, but this advantage is balanced by the tendency of coke to shift slightly every time the bed is filled. This is likely to cause disintegration.

The size of the material is important. The smaller the material the greater is the internal surface area exposed, and the greater the purification and the more efficient the removal of the suspended and colloidal matter.

The efficiency of a contact bed, however, depends very largely upon the admission of air to all parts of the filter during the time the bed is resting empty. Thorough and rapid drainage is therefore of the utmost importance.

For this reason, it is important that the material in a contact bed should not be too small, especially if the liquid to be treated contains an appreciable quantity of suspended matter, as some of this suspended matter will undoubtedly find its way into the interstitial spaces and prevent proper drainage of the bed. This was found to be the case with the fine beds at Devizes and Hampton.

Percolating Filters.—The question of the depth of percolating filters is one of far greater complexity than at first sight appears. At most places the depth has usually been determined by the levels. If plenty of fall has been available, deep filters have been constructed, while at places with little fall the material has usually been laid out in the form of a shallow filter. In other words percolating filters have usually been constructed as deep as levels would allow. In some cases the advantage of deep filters over shallow filters has even been considered sufficient to justify the adoption of pumping.

It has thus been generally accepted that, in the case of percolating filters, the deeper the material the better the result obtained. There appear to be good grounds for this conclusion.

The Commissioners consider that, for practical purposes, within somewhat wide limits of depth, and given ample aeration and good distribution, the same amount of work can be got out of a cube yard of coarse material, whether it be arranged in the form of a deep or of a shallow percolating filter.

Numerous experiments have been carried out with a view to ascertaining whether the nature of the material used for a filtering material has any effect upon the effluent produced, and the result of the York experiments appears to indicate that the materials tested give results in the following order of merit:—

(1) Clinker.
(2) Coke.
(3) Slag.
(4) Broken brick.

The results of the experiments indicate that :—

(1) Better results can be obtained per unit volume from a material with a rough surface than from a material with a smooth surface; and

(2) The extent of the purification effected by a percolating filter varies with the average length of time taken by the sewage to pass through the filtering material, assuming that proper aeration of the filter is maintained.

The depth and size of percolating filters are to a certain extent interdependent and vary over a wide range.

There are in reality three distinct classes of percolating filter in use for the purification of sewage or sewage liquors, viz. .—

(1) Percolating filters constructed of material coarse enough (say, over $2\frac{1}{2}$ inches in diameter) not only to give free access of air to its interior, but also to allow the suspended matter in the liquid free passage through the whole depth of the filter.

(2) Percolating filters constructed of medium-sized material (say,

$\frac{1}{2}$ inch in diameter), which temporarily retards the passage of suspended matter through the filter, while allowing free access of air to the interior.

(3) Percolating filters constructed of very fine material.

The depth of filters varies from 4 feet up to 10 feet.

The general conclusions as to the size and depth of percolating filters are as follows :—

(1) That the deeper the filter, the better the effluent. This holds both for fine and coarse material, assuming good distribution and aeration.

(2) For practical purposes and assuming good distribution, the same purification will be obtained from a given quantity of *coarse* material, whether it be arranged in the form of a deep or of a shallow percolating filter, if the volume of sewage liquor treated per cube yard be the same in each case.

Thus, a filter, 3 feet deep, worked at the rate of x gallons per square yard per day, would give similar results to a filter 6 feet deep, worked at the rate of $2x$ gallons per square yard.

In the absence of clogging, the balance would be slightly in favour of the deep filter, because the greater the depth the more the errors of distribution would be neutralised. There must always be a limit of shallowness (say 3 feet), beyond which it would be unwise to go, for however good the distribution might be, if a coarse filter were constructed very shallow, a considerable proportion of the sewage would pass through by "short cuts."

(3) With regard to filters of *fine* material, if the liquid to be purified were absolutely free from suspended and colloidal solids, and if thorough aeration could be maintained, the statement just made for filters of coarse material might possibly hold good for filters of fine material also. In practice, however, these conditions can scarcely be maintained with large rates of flow, and we think that the greatest efficiency can be got out of a given quantity of *fine* material by arranging it in the form of a shallow filter rather than of a deep filter. But no exact quantitative statement as to the difference in efficiency of the two forms can be made.

It is probable that for the treatment of a strong sewage liquor, the filter should not be quite so shallow as for a weak liquor, but the point has not been fully worked out.

(4) The extent of the purification effected by a percolating filter varies with the average length of time taken by the sewage liquor to pass through the filtering material, assuming that proper aeration of the filter is maintained.

(5) The size of the filtering material should depend, very largely, upon the amount and character of the suspended matter in the liquid

to be filtered. Fine or medium-sized material undoubtedly produces the best effluents, so long as it is kept free from water-logging; but, unless the rate of filtration is slow, such filters soon clog if much suspended matter is contained in the liquid which is being filtered.

The conclusions with regard to the relative efficiency of the working power of contact beds and percolating filters are summed up as follows:—

(1) The amount of sewage which can be purified per cube yard of contact bed or percolating filter varies—within practical limits—nearly inversely as the strength of the liquor treated. This statement is based on the assumption that the size of the material of which the filter is composed is, in each case, suitable to the character of the liquor treated, and that the material is arranged at the proper depth to secure maximum efficiency.

(2) Taking into account the gradual loss of capacity of contact beds, a cubic yard of material arranged in the form of a percolating filter will generally treat satisfactorily nearly twice as much tank liquor as a cubic yard of material in a contact bed.

(3) In the case of sewage containing substances which have an inhibitory effect upon the activity of micro-organisms, the working power per *cube yard of filter of either type may be more nearly equal.* This point, however, is not clearly established.

(4) Percolating filters are better adapted to variations of flow than contact beds.

(5) The effluents from percolating filters are usually much better aerated than the effluents from contact beds, and apart from suspended solids, are of a more uniform character. On emptying a contact bed, the first flush is usually much more impure than the average effluent from the bed.

(6) The risk of nuisance from smell is greater with percolating filters than with contact beds.

(7) It is also found that with percolating filters there is nuisance from flies, especially with filters constructed of coarse material. In the warmer months of the year, such filters swarm with members of the *Psychodidae*, which, though appearing to breed and develop in the filters, may usually be seen in large numbers on the walls of houses and buildings close to or on the works. At Accrington and Dorking a small midge-like fly with a dark body and striped wings has appeared and causes inconvenience to the men by its bite, which gives rise to local irritation.

Comparative Cost of Different Forms of Final Treatment.—In order to give comparative statements of the cost of the complete

treatment of sewage by various processes, careful estimates have been made from which Tables 122—125, pp. 759—762, have been compiled, dealing with land treatment, contact beds, and percolating filters as the final process.

As in the case of the preliminary processes, Table 121, p. 750, the cost of works necessarily varies with local conditions and the figures cannot be regarded as generally applicable. The conditions obtaining in the hypothetical case dealt with in Table 121 are assumed in the cases of Tables 122—125. It is further assumed that in times of storm the dry-weather flow is passed through the filters, and that in each case a satisfactory final effluent is to be produced.

The cost of land throughout has been taken at £100 per acre.

In dealing with Tables 122 and 123, pp. 759 and 760, the soils and subsoils have been divided into the following broad classes.

Class I. All kinds of good soil and subsoil, *e.g.*, sandy loam overlying gravel and sand, as at Nottingham, Cambridge, and Beddington.*

Class II. Heavy soil overlying clay subsoil, as at Rugby.

Class III. Stiff clayey soil overlying dense clay, as at Leicester and South Norwood.

Since variations exist in practice, both as regards the method of purification employed and the extent of cropping, the first of these three classes may be divided into three sub-classes, as follows :—

Class I. { Sub-class *a.* Filtration with cropping.
Sub-class *b.* Filtration with little cropping.
Sub-class *c.* Surface irrigation with cropping.

The method of purification assumed for the other classes of soil are :—

Class II. Surface irrigation with cropping.

Class III. Surface irrigation with cropping. With a heavy soil and clay subsoil, by far the greater part of the purification is effected by surface irrigation, though in exceptional circumstances, such as obtain at Leicester, a good deal is also done by filtration.

In Tables 122 and 123, pp. 759 and 760, the sewage is assumed to be treated by a preliminary settlement in tanks without chemical precipitation. The sludge produced is assumed to be disposed of by trenching the land. The cost of labour is based upon a rate of wages of 21*s.* per week for labourers with a due proportion of the cost of management.

The cost of distribution of sewage on the land is based upon the assumption that one man can attend to the distribution of the sewage for about forty acres, and that the spare time of the men who undertake the sludging of the tanks will be available, and that, in addition to these men, the watermen referred to in the table are employed.

* Particulars of the soils in the farms mentioned have already been given in the chapter dealing with Land Treatment, pp. [illegible].

TABLE 122.—SHOWING TOTAL AREA AND CAPITAL COST OF LAND REQUIRED FOR LAND TREATMENT, PRECEDED BY TANK SETTLEMENT, OF A DRY-WEATHER FLOW OF ONE MILLION GALLONS PER DAY.

Class of Soil and Subsoil, and Method of Working	Volume of Settled Sewage which can be dealt with per Acre per Twenty four Hours.	Area of Land required to deal with a Dry Weather Flow of One Million Gallons.*	Subsidence Tanks. Average Stay in Tanks	Subsidence Tanks. Total Number of Tanks.	Subsidence Tanks. Number of Spare Tanks	Subsidence Tanks. Total Capacity of Tanks.	Subsidence Tanks. Constructional Cost of Tanks †	Sludge. Wet Sludge (90 per cent. Water) produced per Million Gallons from the Average Daily Flow	Sludge. Area of Land estimated to be required for the Disposal of the Sludge	Land. Total Area required	Land. Total Cost at £100 per Acre.	Land. Cost of Laying out including Levelling, Grading, Under-drains, carriers, etc	Total Capital Cost.
	Gallons.	Acres.	Hours.			Gallons	£	Tons	Acres.	Acres.	£	£	£
Class I. Sub-class a. Filtration with cropping	12,000	81	4½	4	1	250,000	2,230	8 to 10	5	89	8,900	6,334	17,464
Class I. Sub-class b. Filtration with little cropping	25,000	40	4½	4	1	250,000	2,230	8 to 10	5	45	4,500	4,589	11,319
Class I. Sub-class c. Surface irrigation with cropping	7,000	145	4½	4	1	250,000	2,230	8 to 10	5	150	15,000	4,494	21,724
Class II. Surface irrigation with cropping	5,000	200	15	8	2	833,333	5,112	17 to 20	12	212	21,000	5,770	32,082
Class III. Surface irrigation with cropping	3,000	334	15	8	2	833,333	5,112	17 to 20	20	354	35,400	7,599	48,111

* These areas are sufficient for the treatment in times of stormwater of three times the mean dry-weather flow

† The estimates of the constructional cost of tanks are strictly comparable with the estimates for similar plant in connection with artificial processes, and have been obtained by preparing drawings and taking out quantities.

TABLE 12[illegible].—GIVING THE COST OF COMPLETE SEWAGE PURIFICATION FOR A DRY-WEATHER FLOW OF ONE MILLION GALLONS PER DAY BY MEANS OF PERCOLATING FILTERS FOLLOWING THE PRELIMINARY TREATMENT.

Preliminary Process	Filtration Process: Rate of Filtration per cub. yard per day Gallons	Filtration Process: Cub. Contents of Filter. Cub. yards	Capital Charges per Million Gallons.*: Medium	Capital Charges per Million Gallons.*: Concrete Floor and Walls	Capital Charges per Million Gallons.*: Rendering	Capital Charges per Million Gallons.*: Sprinklers	Capital Charges per Million Gallons.*: Other Capital	Cost of Labour per Million Gallons	Repair of Sprinklers per Million Gallons	Total cost per Million Gallons	Area of land required Acres.	Complete Preliminary and Filtration Process: Total cost including Preliminary Treatment. See Table 121.: Per million gallons.	Complete Preliminary and Filtration Process: Total cost including Preliminary Treatment. See Table 121.: Per head of population.
			s. d.	£ s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	£ s. d.		£ s. d.	s. d.
1. Continuous flow, settlement with Chemicals ...	150	6 666	7 3	0 9 9	1 0	2 0	10 7	5 1½	0 3¼	1 16 3	0·91	4 18 5	1 2¼
2. Continuous flow, settlement without Chemicals...	75–100	11 494	17 6	1 3 4	2 5	3 2	0 7	5 4½	0 5¼	2 12 8	1·46	4 3 7	1 0
3. Quiescent settlement with Chemicals ...	175	5 714	5 10	0 7 9	0 10	1 7	9 10	5 4½	0 2½	1 11 5	0·73	5 0 4	1 2¼
4. Quiescent settlement without Chemicals ...	100–125	8 925	13 0	0 17 6	1 10	2 4½	1 6	5 4½	0 3¼	2 1 11	1·095	4 1 7	0 11¾
5. Septic Tanks ..	75–100	11 494	17 4	1 3 4	2 5	3 2	0 7	5 4½	0 5¼	2 12 8	1·46	4 7 2	1 0½

... the data given in the Report.—E. J. S

Loan charges for both tanks and land are taken on a basis of thirty years for repayment and 3½ per cent. interest.

Returns from sales of crops are based upon the average figures of thirteen sewage farms which show that the net return, after deducting the agricultural working, may be put at about 30*s.* per acre of the total area of the farm.

The comparisons in Tables 124, p. 761, and 125, p. 762, are confined to percolating filters of coarse material 9 feet deep and contact beds composed for the most part of medium-sized material, but having rather coarse material round the drains and a layer of fine material on the surface.

The filters are all assumed to have been constructed on the same basis. The concrete flooring for the percolating filters, for example, has been assumed to be practically the same thickness as the concrete flooring for the contact beds, and the cost of concrete has been taken at a fixed price throughout. The class of work has been taken to be of the best kind, the walls and the floors of the contact beds, for instance, being made thoroughly water-tight by rendering with cement. The subdivisions of the capital charges have been calculated from the data given in the Report.

Disposal of Sewage Sludge.—Table 126 (on p. 764) summarises the particulars of the cost of removing sewage sludge to sea in six of the principal works in the country where this system is adopted.

The cost of pressing sludge varies materially under different conditions. The wet sludge usually contains from 90 per cent. to 95 per cent. of water and pressed cake about 55 per cent. of water.

Upon this basis the examples may be divided into two groups, as follows :—

Group 1 including towns having a population of about 30,000 and upwards, where the preliminary treatment consists either in chemical precipitation followed by sedimentation or in simple sedimentation, and where the sewage does not contain manufacturing waste of a kind likely to necessitate the addition of an unusual quantity of lime to the sludge before pressing.

Sludge derived from precipitation or sedimentation tanks in these circumstances when pressed requires the addition of about 2 to 4 per cent. of lime, calculated on the pressed cake produced; and the cost of pressing, including lime, fuel, labour, press-cloths, renewals and repairs, but excluding interest and sinking fund, would amount to from 2*s.* to 2*s.* 6*d.* per ton of pressed cake (55 per cent. water). This would be equivalent to from 5·3*d.* to 6·6*d.* per ton of wet sludge, containing 90 per cent. of water.

The interest and sinking fund charges vary from 4½*d.* to 1*s.* 1*d.* per ton of pressed cake produced, or an average of 9*d.* per ton of pressed

which would be necessary if only the dry-weather flow had to be treated; this area would allow of the filtration of three times the mean dry-weather flow, as the filters can be worked at an increased rate during storms.

They go on to say that the usual requirements of the Local Government Board in regard to the treatment of storm sewage should be modified; they are not sufficiently elastic, and, moreover, experience has shown that special storm filters, which are kept as stand-by filters, are not efficient. The injury done to rivers by the discharge into them of large volumes of storm sewage chiefly arises from the excessive amount of suspended solids which such sewage contains, and that these solids can be very rapidly removed by settlement. They therefore recommend, as a general rule—

(1) That special stand-by tanks (two or more), should be provided at the works and kept empty for the purpose of receiving the excess of stormwater which cannot properly be passed through the ordinary tanks. As regards the amount which may be properly passed through the ordinary tanks, our experience shows that in storm times the rate of flow through these tanks may usually be increased up to about three times the normal dry-weather rate without serious disadvantage;

(2) That any overflow at the works should only be made from these special tanks, and that this overflow should be arranged so that it will not come into operation until the tanks are full;

(3) That no special storm filters should be provided, but that the ordinary filters should be enlarged to the extent necessary to provide for the filtration of the whole of the sewage, which, according to the circumstances of the particular place, requires treatment by filters.

(4) As regards the overflow from the outfall sewer to the stand-by tanks, the size of the stand-by tanks, the amount of storm sewage which should be filtered, and the arrangements generally for dealing with storm sewage at the outfall works, the Rivers Board, or the County Council in areas in which no Rivers Boards have been established, should have similar power to that which we have proposed in regard to overflows on branch sewers, and the Local Authority should have a similar right of appeal to the Central Authority.

It is considered impracticable to dispense altogether with storm overflows on drainage sewers, but it is recommended that they should be used sparingly and should usually be set so as not to come into operation until the flow in the branch sewer is several times the maximum normal dry-weather flow. The general principle should be to prevent such an

amount of unpurified sewage from passing over the overflow as will cause a nuisance.

The Choice of a Method of Sewage Treatment.—The selection of a method of sewage disposal, and the settlement of details in connection with any method which it is proposed to adopt, should depend primarily on local conditions.

If a sufficient quantity of good land, to which the sewage can flow by gravitation, can be purchased for about £100 an acre, land treatment would usually be the cheapest method to adopt. Or, if the case were one in which it was necessary to obtain a high-class effluent, it might be cheaper to pay a somewhat higher price for good land, rather than to adopt artificial treatment, because effluents obtained from the treatment of sewage on artificial filters, as usually carried out in practice, are generally distinctly inferior to those obtained by the treatment of sewage on good land, and some addition to the ordinary artificial plant would therefore be required. On good land, a sewage of average strength, from which the major portion of the suspended solids have been eliminated by tank treatment, can be treated at about the rate of 30,000 gallons per acre per day, with the production of a high-class effluent. If the land available were of only medium quality, capable, say, of treating only half this quantity, its use might still be economical, if it could be acquired at about £50 an acre.

In cases where only clay land was available, it would generally be cheaper and more satisfactory to provide artificial filters.

In considering the question whether land or artificial treatment should be adopted, the situation and levels of the land available are, of course, important factors And whatever system is adopted, it is essential that the works should be so situated as to be capable of extension.

As regards the selection of an artificial process, the following are the broad generalisations :—

The selection of the preliminary process should depend mainly upon local circumstances and upon the facilities offered for the disposal of sludge.

If the circumstances were such that considerable quantities of sludge could be easily and effectively disposed of, say, as wet sludge by sending to sea or by trenching in soil, or as pressed cake by sale or gift to farmers, it would probably be best and cheapest to adopt a preliminary process which removed as much of the suspended matter as possible from the sewage. If, on the other hand, it were imperative to have as little sludge and as few sludging operations as possible, then septic tanks or continuous flow settling tanks might be cheaper. The size of the

place and the question of smell are also factors of primary importance in the selection of the preliminary process.

Single contact beds will, generally, only yield a good effluent where the sewage to be purified is weak, and then only after good preliminary treatment. For the purification of partially settled weak sewage and for well as also for partially settled sewage of average strength, if the case is one in which a good effluent is required, double contact is necessary, while, if a strong sewage has to be purified, triple contact is necessary unless the preliminary treatment is exceptionally good.

In nearly every case a greater rate of filtration can be adopted if the material is arranged in the form of a percolating filter than if it is used in contact beds. The rate of filtration per cube yard in the case of percolating filters may, generally, be double, or nearly double, that which is permissible in the case of contact beds.

As regards percolating filters, where the liquor to be treated is weak, and the preliminary treatment has effectively removed the greater part of the suspended matter, it is probably best, in most cases, to use fine material arranged in the form of shallow filters.

Where the sewage to be treated is strong, and especially if the preliminary treatment leaves a considerable quantity of suspended matter in the tank liquor, it is best to use deep filters of coarse material.

Where the liquor to be treated contains much suspended matter, it is usually advisable to construct percolating filters of coarse material, *whatever the strength of the original sewage.*

For sewages of about average strength, from which most of the suspended matter has been removed in the preliminary treatment, either coarse or fine material may be used.

It may be added that, with very well clarified weak sewage, filters with a top layer of very fine material, such as sand, can be made to give good results with a rate of filtration of 400 or even 500 gallons per cube yard per day. In this case, however, the material must be washed (*e.g.* by upward flow of tank liquor) at short intervals of, say, a week.

Standards of Purification.—The Commission have concluded that it is desirable for the Central Authority to determine the nature of tests which are to be applied for the purpose of standards, and that it should be the duty of the Rivers Board (in the absence of such Board, the County Council) to determine from time to time, subject to appeal to the Central Authority, what standards should be adopted.

In the first instance it would be convenient that the Central Authority should prescribe one standard for all non-tidal waters, in

place of the existing statutory provisions. It would then rest with the Rivers Board or County Council to fix, subject to appeal to the Central Authority, a higher or lower standard, in any case in which they were of opinion that the circumstances required or justified a different standard.

It is further recommended that no action should be allowed to be brought in respect of damage alleged to be due to the discharge of an effluent which complies with the standard fixed for the water into which it is discharged, but that in such cases complaint should be made to the Central Authority, and, if a *prima facie* case is made out, that Authority should ascertain whether the complaint is well founded, and should be empowered to fix a different standard if the circumstances are shown to require it.

In cases where it is alleged that the effluent does not comply with the statutory standard, and that damage is caused by the discharge of such effluent, action should be brought in the ordinary courts.

But any questions arising as to whether the effluent complies with the statutory standard, or as to whether the damage has been caused by the discharge of the effluent in respect of which complaint is made, should be referred by the Court to the Central Authority for determination. The cost of such determination should be borne by the parties to the action in such proportions as the Court may determine.

Power should be conferred on the Central Authority to suspend from time to time the operation of any standard, to allow time for the construction of works, or for any other reason which, in their opinion, justified such suspension.

For the guidance of Local Authorities a provisional standard of purity is given which will be generally satisfactory if the effluent complies with the following conditions.

(1) That it should not contain more than three parts per 100,000 of suspended matter; and

(2) That, after being filtered through filter paper, it should not absorb more than:

- (*a*) 0·5 part by weight per 100,000 of dissolved or atmospheric oxygen in 24 hours;
- (*b*) 1·0 part by weight per 100,000 of dissolved or atmospheric oxygen in 48 hours; or
- (*c*) 1·5 parts by weight per 100,000 of dissolved or atmospheric oxygen in 5 days.

Central Authority.—Finally the Commissioners repeat the recommendation given in their previous Reports in favour of the appointment of a Central Administrative Authority to deal with all questions arising

with reference to sewage matters, and to act as a court of final appeal with reference thereto.

Among the more important questions which have to be dealt with under the new conditions of administration contemplated are the following:

(i.) Disputes between local authorities and manufacturers as to the terms and conditions on which trade effluents shall be admitted into sewers.

(ii.) The control of shell-fish layings so as to prevent the taking of shell-fish for human consumption from positions in which they are liable to risk of dangerous contamination.

(iii.) The protection of water supplies from pollution.

(iv.) The collection of information as to the water supplies available in various parts of the country.

(v.) The collection of information as to the need of water in various parts of the country.

(vi.) The settlement of standards for different reaches of water.

(vii.) Conferring powers on local authorities, in suitable cases, to provide separate systems of sewers for surface water and to enforce the provision of separate drains.

(viii.) The settlement of questions as to the extra amount of sewage which a local authority should be required to treat during storms.

There are also numerous questions in regard to the purification of polluting liquids which, in the interests of the public, have still to be worked out, and it is essential that the Central Authority should be properly equipped for undertaking such special investigations as they may from time to time find necessary, and for collecting and collating the work done by others.

Since 1898 considerable developments have taken place in regard to the disposal of sewage, and there is every reason to think that further changes will occur in the future.

Unless the Central Department keep in close touch with all such changes, and from time to time report on them, it is not possible for local authorities throughout the country fully to utilise the results of valuable work which is being done at many places, and hence, to perform their duties in the most economical as well as efficient manner.

Local Government Board Inquiries.

Local authorities are required by the Public Health Act, 1875, sect. 15, to keep in repair all sewers belonging to them and to make such sewers as may be necessary for effectually draining their district.

Sect. 17 of the same Act prohibits the local authority from making or using any sewer for the purpose of conveying sewage or filthy water into any natural stream or watercourse, or into any canal, pond or lake until such sewage or filthy water is free from all excrementitious or other foul or noxious matter such as would affect or deteriorate the purity and quality of the water of such stream, watercourse, canal, pond or lake.

By sect. 27 the authority is authorised to—

(1) Construct works for the purpose of sewage disposal.

(2) Contract for the use of, purchase or lease of land or works for sewage disposal.

(3) Contract to supply, for any period not exceeding twenty-five years, any person with sewage.

These duties are cast upon *the local authority by the Act, and they* are entitled to carry out those duties in any manner they think fit, provided

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For the Local Government Board's Revised Requirements (1909) with respect to Sewerage and Sewage Disposal, see Appendix III., pages 875—880.

("Sanitary Engineering" Vol 2, page 772)

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for the purposes of the Act subject to the approval of the Local Government Board ; and in order to secure the sanction of the Board the works must be of a permanent character and of an adequate nature.

Sect. 234 contains regulations as to borrowing as follows :—

(1) Money may not be borrowed except for permanent works (including under this expression any works of which the cost ought in the opinion of the Local Government Board to be spread over a term of years).

(2) The sum borrowed shall not at any time exceed, with the balances of all outstanding loans contracted by the local authority under the Sanitary Acts or of this Act, in the whole the assessable value for two years of the premises assessable within the district in respect of which such money may be borrowed.

(3) When the sum to be borrowed with such balances (if any) would exceed the assessable value for one year of such premises the Local Government Board shall not give their sanction to such loan until one of their inspectors has held a local inquiry and reported to the Board.

(4) The money may be borrowed for such time, not exceeding sixty years, as the local authority with the sanction of the Local Government Board determine in each case.

It is the practice of the Local Government Board to hold local inquiries

through one of their engineering inspectors in almost every case in *which their sanction is sought whether the amount brings the total loans* within the limit fixed by the Public Health Act, 1875, sect. 234 (3), or not.

The lengths of terms for repayment of loans vary with the character of the works; usually fifty years is given for land, thirty years for works of sewerage and the permanent works of disposal; fifteen years for machinery and ten years for fencing. The Board will not allow any payment to a salaried official of the local authority to be included in a loan except in cases where the clerks are solicitors in practice, when they will allow legal costs for conveyance of land, etc.

The procedure to be followed commences with a formal resolution of the local authority approving of the scheme and asking the Board to sanction a loan of a definite sum for carrying out the works. This formal application must be forwarded to the Board accompanied by detailed plans and sections of the works and an estimate of the cost in duplicate on printed forms supplied by the Board and signed by the engineer.

The plans may be published ordnance maps of the district if revised and brought up to date, tracings on cloth or sun prints, and they must comprise :—

(1) A 6 inch scale ordnance map, showing the whole of the area to be rated for the works, on which the intended works must be drawn with red lines.

(2) A general plan of all sewers and works, which may be an ordnance map of the $\frac{1}{2500}$ scale, and should show all sewers and the positions of all manholes, lamp-holes, flushing chambers, purification works and outfalls.

(3) Longitudinal sections of all intended sewers. These should be plotted on sheets of double elephant size, and not on long rolls; they should be referenced with letters or numbers at the end of each section and at all cut lines and junctions of tributary sewers, and corresponding letters or numbers should be marked on the general plan. All levels should be reduced to ordnance datum, and the levels of the ground should be figured in black ink at all important points. The levels of the inverts of the sewers should be figured in red at every change of gradient, also the gradients and depth below bench marks. The positions of manholes, lamp-holes and flushing chambers must correspond with the plans. The horizontal scale for sections may be $\frac{1}{500}$ and the vertical scales large enough to check the figured heights and depths; 20 feet, 10 feet or 4 feet to the inch being the usual scales adopted.

(4) Detail drawings of manholes, lamp-holes, flushing chambers, etc. These should be $\frac{1}{4}$ inch or $\frac{1}{2}$ inch to the foot scale.

(5) A site plan of the sewage disposal works drawn to a scale of $\frac{1}{500}$, or 30 feet or 20 feet to an inch, with spot levels reduced to ordnance datum. It should show the boundaries of the land to be taken and the general arrangement of the works in block plan and the position of carriers and under-drains if land be used as a final process.

(6) Detail plans of all buildings, reservoirs, tanks, filter beds, bacteria beds, carriers, effluent chambers, etc., must be included, and these must be drawn to scales of sufficient size to disclose the mode of construction in every detail; in fact, it is usual to make these drawings so that they may be subsequently used as contract drawings. The levels of all important points such as inlets, inverts, and outlets of tanks and filters, sills of overflows, etc., reduced to ordnance datum should be marked in figures on these plans.

(7) If the final effluent is to be discharged into tidal waters a special plan showing the outfall must be prepared for submission to the Board of Trade.

The estimates must be prepared in detail on printed forms which can be obtained from the Local Government Board, of which the following is a copy:—

WORKS OF SEWERAGE.—ESTIMATES AND DETAILS.

Name of Council

Will any of the proposed works be outside the limits of the District of the Council, and if so, in what Parish and Sanitary District will they be situate?

In the case of a Rural District (a) Name of Contributory Place for which the works are required *(b) If any of the works are to be executed in another Contributory Place, name of such Contributory Place*

In the case of an Urban District, state whether all the streets to be sewered are highways repairable by the inhabitants at large

BRICK SEWERS.

Name of Street or Road.	Gradient	Average depth of Sewer.	Internal Diameter or Dimensions of Sewer	Length in yards	Price per lineal yard	Amount.			Remarks.
						£	s	d.	

N B.—State whether the sewers are to be constructed of common bricks, or of radiated bricks, or of rubble, concrete, or some other material. Radiated bricks should be used when they can be obtained.

Side junctions for house drains should be inserted in brick sewers at the time of construction Junction pipes should be provided on all pipe sewers

Forward a description of the subsoil to the extent of the greatest depth of any sewer-trench, tunnel or heading, ascertained by trial holes or by borings at certain distances.

Main sewers should, as far as practicable, be laid at such depth and with such gradients as to afford means for draining the cellars and basements of houses.

EARTHENWARE PIPE—SEWERS AND DRAINS.

Name of Street or Road	Gradient	Average depth	Dimensions	Length in yards	Price per lineal yard.	Amount			Remarks
						£	s	d	

N.B.—Describe the pipes

Describe the materials to be used in making the joints, and the mode in which the joints are to be made good.

All sewers laid under roadways should have at least four feet clear of cover. When this is impracticable the pipes should be surrounded with six inches of concrete.

MANHOLES, GULLIES AND VENTILATORS.

Description of Work.	Number.	Price	Amount			Remarks.
			£	s	d	
Manholes, with movable covers, complete						
Gullies, complete						
Lampholes, complete						
Sewer and Drain Ventilators						

N.B.—Describe the manholes, lamp-holes, gullies and sewer ventilators.

OUTFALL WORKS, &c.

Description of Work.	Amount			Remarks
	£	s	d	
Particulars of Outfall Works in detail				
Particulars of Special Flushing Works in detail				
Particulars of Pumping in detail				
Particulars of Sewage Irrigation Works in detail . . .				
Particulars of Sewer and Drain Flushing Arrangements in detail				
Other Expenses, if any . .				

Date ____________ *(Signed)* ________________

N B.—This form should be signed by the engineer of the proposed works

On receipt of these documents the Board appoints a date on which one of its engineering inspectors will hold a local inquiry. Notice of this date will be sent on printed forms to the clerk to the council, who is directed to have the same posted in certain places. The notice states the name of the inspector, the sum of money to be borrowed, the purpose for which it is designed, the time and place of the inquiry, *and that the inspector will be prepared to hear any persons interested* on the subject of the inquiry. No other notice is given or required than this, and it therefore behoves the opponents of any scheme if they desire to oppose the application, to take steps to keep themselves posted of the course of events.

The inquiry is usually held in the Council Chamber of the Council, and the hour 10 a.m. This time is frequently objected to by ratepayers who cannot afford the time to attend during the working hours of the day, but it is very rarely that the Board will alter the time

If the application be not opposed, the case for the local authority is presented by the Clerk to the Council, assisted by the engineer, medical officer, and other officials, and the attendance is usually limited to one or two members of the Council and a few ratepayers.

On the other hand if there be an organised opposition, there may be counsel and an array of expert witnesses on both sides, and the inquiry is then conducted on the same lines as an ordinary Court of Law, and there may be such a large attendance of the members of the Council and the general public that it is necessary to adjourn the meeting to some large public hall; such inquiries sometimes last several days and create a large amount of interest.

Strictly speaking, the only question to be inquired into is the merits

of the scheme put forward by the Council; it usually happens, however, that the most effective method of combatting the scheme is to show that there is a better alternative, and it is then a matter of argument how far the counsel and witnesses can go in referring to the alternative which is not before the tribunal; a certain amount of latitude is usually given by the inspector in this direction, and it not infrequently happens that a scheme put forward by the opposition is manifestly so superior to the original proposal that the application of the Council is refused by the Board; in this event the Council occasionally adopt the alternative and make a fresh application for a loan to carry it out.

The inspector requires proof of the posting of the notices of the inquiry, and after taking the names of those appearing on behalf of the local authority and the opposition, he must be furnished with particulars of the area, population, rateable value and outstanding loans of the district

but that for such works as sewers is sufficient to provide for the reasonable future population to be drained; and that for such works as filters, engines and pumps, etc., the units proposed are such that additional units can be added as the population increases without upsetting the proposed installation or requiring an extension of the site.

In the same way he must ascertain the present dry-weather flow of sewage; or in the absence of this (*e.g.* if the sewers are not sufficiently well organised to enable gaugings to be made) he must give details of the water supply separating the domestic from the trade consumption, and an estimate of the future quantity of sewage to be dealt with, and the quantity of rainwater to be admitted to the sewers. Particulars must be given of the proportion of population using water closets and baths, and of the character of the trade waste (if any).

The sewers proposed to be constructed must be described with particulars of sizes, depths, gradients, velocities, manholes, flushing arrangements, methods of ventilation, quality of pipes and methods of jointing.

On this part of the subject he must expect to be asked as to the nature of the ground to be passed through and give an estimate of the quantities of rock, running sand or other exceptional strata, and this information should be supplemented with details of trial holes, and as to mining operations in the neighbourhood.

Storm overflows must be clearly marked on the plans, and details given of the construction and degree of dilution of the sewage at which they will come into action. Unless under very exceptional circumstances the Board will not allow any form of overflow except a relief weir over which the sewage can discharge when it reaches the predetermined number of dilutions of the dry-weather flow.

When dealing with the purification works, the first question is the land, and the Board will in every case require information as to the ownership. If the local authority are already in possession of the land, it must be shown how they became owners and that it is competent for them to devote it to the particular purpose; if the land is to be purchased or hired, a provisional agreement must be produced showing the terms on which it can be acquired: or if compulsory powers of purchase are asked for, it must be shown that the owner is not a willing seller.

If the land is to be used for filtration or irrigation purposes, trial holes must be opened to enable the inspector to ascertain for himself the suitability or otherwise of the soil for the purpose in hand. Full particulars of area and allocation to tanks, filters, buildings, roads and actual irrigation area; the levels as already stated must be disclosed by spot levels on the site plan.

(3) Overflows in unsuitable places.
(4) Land not suitable for irrigation or filtration.
(5) Tanks and filters not adequate.
(6) Sludge disposal unsatisfactory.
(7) Danger of contamination of water supplies.
(8) Purification works too near to dwelling-houses.

Some of these objections are fatal to the whole scheme and involve the preparation of entirely new proposals and a further inquiry, whereas others may be met by modifications which may or may not receive the sanction of the Board without a public inquiry.

CHAPTER XXI.

DESTRUCTORS.

THE earliest systems of disposing of town refuse consisted in the establishment of refuse tips. Usually these were in places where low land required to be raised or old quarries or clay pits were to be filled up.

Where sites of the above description were not available it was a common practice in the outskirts of many towns to spread the refuse on land which subsequently would be used for building purposes and a most objectionable and insanitary condition of things was the result.

This system of disposing of refuse is now recognized by all authorities as being most objectionable and detrimental to health owing to the spreading of disease by dust and flies into the houses in the neighbourhood as well as from the smells arising from the decomposing of the

Another method of disposing of refuse is in vogue at towns near the sea coast, namely to tip the refuse into the sea.

This system is usually cheaper than burning, but there are many reasons which tend to make it unsatisfactory.

Owing to bad weather it often happens that the barges or steamers used for discharging the refuse cannot proceed to sea and the refuse has to be stored sometimes for long periods in positions where it is highly objectionable.

Quantities of refuse dumped at sea find their way to the beaches of sea-side resorts in the neighbourhood, and this objection is likely to increase rather than decrease.

Liverpool may be taken as an example of a town which commenced years ago with a sea-disposal system and has since largely discontinued it, and destructors are now used for the greater part of the refuse.

The small number of towns which could economically utilize this system of disposal is an indication of its weakness.

Destruction by fire is without doubt the most sanitary and, taken all round, the most economical system of refuse disposal, and the development of the modern refuse destructor has resulted from the careful study of the problem by numerous firms engaged in the manufacture of this class of municipal establishments.

Object of Destructors.—The object of a destructor is to convert the organic matter contained in town refuse into fixed and harmless products by means of combustion; the organic products present are thus converted into the comparatively, if not absolutely, harmless forms of water vapour, carbonic acid gas, and nitrogen, all of which are commonly found in ordinary atmospheric air. In order to avoid a nuisance, it is necessary that complete combustion should be ensured, and all dust arrested before the gases escape up the chimney.

For complete combustion a high temperature in the furnace must be maintained, and this demands a strong draught and a well distributed supply of air to the burning fuel. The lowest temperature necessary to deodorize the noxious fumes from burning ashbin refuse is 1,350° Fahr., but a higher temperature, of not less than 2,000°, is essential to ensure the destruction of all disease forms, as well as the gases and offensive vapours given off By this means an efficient calcination and the reduction of all refractory materials can be effected so as to produce the minimum percentage of clinker and ash, of such a quality as will enable them to be utilized, and so not only save the expense of carting them away and tipping to waste, but actually become a source of revenue; this is a powerful argument in favour of the employment of high-temperature destructors. An average residue of about one-third of the weight of the unscreened ashbin refuse

of clinker and ash is thus left, the two-thirds having been destroyed by fire.

Town's refuse consists normally of ashes, cinders, breeze, dust, animal refuse, such as bones and the entrails of rabbits, fish, fowls, etc.: vegetable matter such as potato and apple peelings, cabbage leaves, straw, paper, rags, tins, crockery, glass, iron, and other miscellaneous matters swept up in the streets and markets.

In what are known as the privy-midden towns of the North of England the mixture of ashes and general refuse is supplemented by solid and liquid human fæces, and in some few instances sewage sludge is also mixed with the refuse.

The large proportion of organic matter in town refuse causes putrefaction to take place more or less quickly, and then nuisance arises from bad smells, particularly in hot weather.

Much of this trouble might be avoided if householders would take the trouble to burn their refuse for themselves. There is not the slightest reason why every housewife should not destroy by fire all the organic refuse manufactured in her own house and leave nothing but ashes and dust for removal by the local authority, and there can be no doubt that by adopting such a system the health of crowded communities would be vastly improved.

Such a state of things, however, is not likely to arise, at all events until the general public take a greater interest in, and are better educated about sanitary problems, than they are at present.

But even when the best possible has been done to reduce the putrescible matter in the ordinary domestic refuse, there is still the privy-midden refuse above referred to, and the refuse collected by the public authority, from streets, markets, alleys and yards, to be dealt with.

The calorific value of the refuse varies in different localities, and generally it may be said that where coal is cheap there the inhabitants are wasteful in its use and consequently the refuse has a high calorific value.

The quantity of refuse per head of the population varies to a very marked degree. In London the collection in the Strand district is at the rate of 9 cwt. per head per *annum* of the population; in St. Pancras, 6·66 cwt. per head; in Shoreditch, 3·5 cwt. per head; and the general average for the whole of the Metropolis may be taken at 5 cwt. per head. In the South of England the amount of refuse is usually 5 cwt. per head; in the Midlands, 7 cwt., and in the North 10 cwt. per head.

With an efficient special furnace about 6 cwts. of ashbin refuse can be burnt per hour with a good natural draught on a fire-grate 25 square

feet in area. This may be increased to one ton per hour with a f draught or air pressure of from $1\frac{1}{2}$ inches to $3\frac{1}{2}$ inches of water.

Destructors should be so designed as to involve the least pos expense in working; the amount of handling which the refuse h undergo should be arranged so as to reduce it as far as practicable apparatus at the same time should not be complicated, as, in the pre of dusty and dirty material, it is sure to deteriorate very rapidly.

The earliest destructors were erected in this country in 1876, the late Mr. Alfred Fryer built his first destructor in Manchester in the following year at Beckett Street, Leeds.

Both of these destructors are still in use, and at both cities addit improved destructors have been built.

The early destructors were worked with natural draught and paratively speaking low temperatures, with the result that the or matter in the refuse was not completely converted into simple g and large quantities of dust were carried through the furnaces discharged from the chimneys.

The first attempt to meet these difficulties was the introducti the "Jones cremator," which consisted of a second furnace fired coke between the destructor cell and the chimney.

The products of combustion from the cell were conducted thr the cremator in which a temperature ranging up to about 1,100° was obtained.

The next great stride made was the introduction of forced draug This principle was first introduced with a view to increasing quantity of refuse which could be destroyed in a cell of a given si it was felt that the quantity destroyed was out of all proportion t sizes of the cell, but incidentally much higher temperatures realized, ranging up to as much as 3,000° Fahr., and this led th to the utilization of the heat produced for power purposes.

Before considering the various destructors on the market it perhaps, be well to say a few words as to the principal poin difference.

In all the earlier types of destructor a drying-hearth was consi to be an essential part of the apparatus, this hearth being arrang that the wet refuse should have a preliminary drying process bef actually reached the firing grate.

Whilst it is desirable that the refuse to be burned should be a as possible, experience shows that the drying-hearth, as at first arra was liable to give off gases in such a position that they wer completely burned before being discharged into the chimney flue.

Those destructors which still retain the drying-hearth are designed so that the fumes arising from the drying process are c

over the hottest part of the fire, and subsequently into a compartment known as the combustion chamber before reaching the boilers or the chimney flues.

Further experience has shown that with forced draught and careful firing the drying process is unnecessary, and consequently the drying-hearth is not now considered to be an essential part of a destructor.

It is necessary for successful working that there shall be in the passages between the furnace and the chimney a space in which the products of combustion may expand and be brought to a low velocity in order to deposit the dust which must inevitably be drawn out of the furnace whether the draught is natural or forced.

The boilers should not be fixed too near the furnaces, otherwise they have a tendency to cool the products of combustion before they reach their maximum temperature: there should be a combustion chamber between the furnace and the boiler to prevent this taking place.

When comparing the results obtained by various destructor plants, regard must be had to the cost of labour in firing and clinkering. It is possible, by increasing the amount of labour, to consume a much greater quantity of refuse in the same furnace, but there is an economic point at which the total cost per ton of refuse burnt is at a minimum, and any increase in labour beyond that point results in an increased per cost ton of refuse burnt.

It is also necessary to take into consideration the calorific value of the refuse, for, as already pointed out, this varies in different districts and must be allowed for.

The systems of discharging the refuse into the cell vary; the earlier installations having a top feed down an inclined shoot. This has been varied by a front feed in which the whole of the refuse is shovelled in the front of the furnace, a back feed in which the material is shovelled into the back of the furnace, and various patent mechanical charging apparatus such as Boulnois & Brodie's, Horsfall Tub System, Heenan's & Marten's. The latter is used exclusively in connection with the "Meldrum" destructors.

These different methods of charging all have their special advantages and each have their advocates.

In the top feed the refuse to be burned is tipped direct from the collecting carts on to the feeding-floor, which is above the furnace, and in which feeding-holes are provided leading direct to the drying-hearth or furnace, and the refuse is pushed down the feeding-hole into the furnaces.

This operation is one which cannot be easily regulated, and the material to be burned has to be subsequently raked forward from the drying-hearth or feeding-hole on to the furnace bars by means of

long rakes worked through the clinkering doors at the front of the furnace.

Where the cells are arranged back to back this arrangement cannot be modified, as it is impossible to arrange an opening at the back of the cell.

This method of charging is open to the strong objection that large quantities of refuse are stored on the feeding-floor, which is more or less heated by the cells beneath.

The result is a certain amount of cooking of the damp refuse exposed to the atmosphere and the giving off of offensive smells, also the creation of fine dust which is liable to be blown about, especially when charging operations are going on.

The dispersal of this fine dust may be minimized by closing all doors in the building over the feeding-floor, but in practical working this is found to be almost impossible, and men working at the charging operations, for their own comfort's sake, allow the doors to be open to afford sufficient ventilation and movement of air to discharge the dust and carry it and the smells away to the surrounding district.

It may be said that at the present time with the efficient destructors now at work, the only nuisance resulting from the destruction of refuse is that arising from the refuse stored upon the premises prior to its being cremated, and in the top-feed type of destructor this nuisance is at a maximum, largely owing to the refuse not being kept cool.

In the case of front-feeding the refuse is usually tipped from the collecting carts into a storage hopper which discharges through doors fixed slightly above the firing floor and about on a level with the furnace mouth.

It is then shovelled direct from the storage hopper into the cell, and this represents charging in its simplest and most direct form.

In the front-feed type of furnace there is no drying hearth and the refuse is shovelled direct on to the firing-grate, care being taken by frequent charging to keep the fire at a uniform depth and to avoid as far as possible damping down any part of the fire, so that complete combustion is obtained all over.

The whole of the work of feeding is done with a shovel, and there is no dragging or raking of material forward as in the top or back feed arrangements. The whole of the labour being expended at the front of the cell without additional labour for dragging, spreading or levelling, makes this system of feeding an economical one, and some of the lowest labour costs for burning are obtained with the front-feed type.

It is objected by some that with the front shovelling feed the clinker is withdrawn from the same door as that through which the refuse is fed.

This objection, however, is not a valid one, as experience has shown that there is no difficulty at all in arranging the clinkering operations so as not to interfere with the feeding, and it must be borne in mind that every steam boiler which is hand-fired is open to the same objection. An examination of the clinker produced by front-feed furnaces demonstrates beyond doubt that there need be no reason why there should not be complete combustion with a front-feed type of furnace.

The main advantage presented by this system of firing is the ease with which the fire can be regulated, the refuse being fed into a hot and active cell in small quantities, and by this means rapid distillation and cremation are provided and a uniform temperature is maintained.

In dealing with the firing of coal into an ordinary boiler the main object of all stokers, whether human or mechanical, is to apply fuel in small quantities in the proper place at frequent intervals, and this, it is contended, can be better done by hand work in a destructor with a front-feed than by any other system.

In the back-feed type of destructor the refuse is tipped usually to a feeding-floor or hopper, from which it is shovelled through an opening at the back of the furnace on to a drying-hearth at the back of the grate.

This system of firing involves the raking forward and spreading of the material from the drying-hearth on to the firing-grate, and this operation can only be performed in the same way as with the top-feed, namely, by rakes worked from the front of the furnaces through the clinkering doors.

It will thus be seen that there is an additional operation in this system over the front feed, and that the only material difference between the top and back feeds is that the refuse is not stored upon a platform over the cells.

In most back-feed installations the refuse to be stored is tipped on to the charging or feeding-floor, and is shovelled thence into the furnace, but there is no reason why there should not be an arrangement of hoppers similar to the front-feed, in which the refuse could be stored, and thus avoid the objection of having a quantity of refuse stored upon an open floor.

The regulation of the fire and the labour necessary to drag and level the refuse from the drying-hearth to the fire is less than in the case of a top-feed cell, and the cost of labour is found to be less in this system than in the top-feed type.

Turning next to the mechanical systems of feeding, in Boulnois & Brodie's patent, which is manufactured by Messrs. Manlove, Alliott & Co., wrought-iron trucks are provided about 5 feet wide and 3 feet deep;

each truck is divided into compartments, each of which contains sufficient refuse for one charge of the furnace.

The trucks run on rails placed over the cell, and are moved by means of a winch and endless chain.

The trucks are arranged with a tipping-floor at such a level that the refuse can be shot direct from the collecting carts into the trucks.

This involves an additional platform about 18 feet above the clinkering-floor level, and the type of destructor must be a top feed.

When it is desired to charge a cell, a truck is moved until one of the compartments is immediately over the feeding-hole of the cell.

Each compartment of the trucks has a sliding door at its base, which is moved away when the sliding door covering the opening of the furnace is removed. The refuse then falls direct from the truck on to the drying-hearth.

The advantage of this system is that the storage of the refuse is in a portable form and is cool, and a further advantage is found in the absence of labour in handling the refuse, which makes the process cleanly and sanitary.

There is, of course, an additional capital cost, and the system involves the dragging of the refuse and spreading it over the grate.

In the Horsfall Direct Charging System a large bin or hopper is arranged on the top of the cells, the top of the bin or hopper being level with the tipping floor, its base being formed by an extended table above the drying-hearth

The refuse is tipped direct into the hopper or bin and is fed from the bin on to the drying-hearth.

To prevent the refuse in the bin from catching fire, troughs filled with water are arranged round the feed openings, and the lids covering the openings into the cells, each weighing about $1\frac{1}{4}$ tons, are suspended from travelling winches running on rails.

These winches are so arranged that by a few turns of the handle the covering lids can be raised a few inches above the trough and water seal, and they are then carried clear of the opening.

The objection to this system is the long rake which has to be used by the stoker to drag the refuse forward from the drying-floor on to the grate. This is very difficult and heavy work, and during the operation large volumes of cold air pass into the cell through the open door, tending to reduce the temperature of the furnace.

Messrs. Horsfall have introduced a tub-feed system, in which the refuse is discharged from the carts into storage tubs fitted with suitable covers, which enable them to be closed when not actually in use, and the storage thus takes place in closed vessels.

The refuse is discharged direct from the tubs into the cells through

a water-sealed charging door, and is then raked forward as in the previously described system.

For a further description of this, see the description of the Horsfall destructor which follows later.

In the case of Marten's patent charging apparatus, the apparatus consists of a wrought iron hopper placed on the top of the cell and immediately over the drying-hearth.

The hopper is provided with travelling gear which enables it to be moved to any cell required.

The refuse is tipped from a platform into the hopper and is charged direct into the cell.

The cell is so arranged that the mass of refuse can be readily raked forward and levelled, it being possible to reach it both from the side and back of the cell, and the stoker is able to push a great deal of it forward from the back, where it is not necessary to use a long rake and the workman is enabled to carry on his operations under cool conditions.

The cost of working by this system appears to be exceptionally low.

The chief objection to the system is the question of storage, as the system requires storage in carts This involves the provision of a large number of additional carts, which increases the capital cost.

The sliding hopper base covering the charging hole is perfectly gastight, and there is no escape of gases during the charging operation, and in the event of anything happening to the hopper the destructor can be used as an ordinary top feed.

This form of apparatus involves a high charging platform about 18 feet above the clinkering floor.

In the Heenan system of feeding a modification has been introduced with a view to reducing the labour involved in spreading the material over the grate.

A ram is placed in such a position that it can push the refuse from the hopper on to the grate. The working parts of this system are simple, and it is worked by power gear.

The stroke of the ram is, however, necessarily limited, and the varying nature of the refuse to be dealt with makes it almost impossible for a system of charging of this character to be perfect, and it is found necessary to supplement the work of the ram by hand labour.

Turning next to the question of forced blast, we find that there are two systems in use, namely, steam jet blowers and fans.

The relative advantage of these two systems is again a question about which much has been said and written.

The advocates of the fan system point out that, in actual steam consumption, their method has an advantage over the steam jet, and this apparently is the chief point which can be claimed for it.

The steam jet, however, is found to be equally as efficient as the fan, and in point of first cost and maintenance it has a great advantage over the fan whilst it is an exceedingly simple appliance and cannot very well get out of order.

On the other hand, fans are costly and liable to get out of order. Depreciation on moving machinery is always an important item, and they require far more attention than a steam jet.

The consumption of steam by steam jets is, however, an important matter, especially where the heat from the destructor is to be utilised for power purposes. The steam jet may use anywhere between 10 per cent. and 40 per cent. of the total steam produced Whereas with a fan blast only some 3 per cent. to 5 per cent. of the steam evaporated in the boilers is required to operate the fan engine.

It is objected by the advocates of the fan that, with a steam jet, moisture may be deposited upon the cooler parts of the boiler and economiser tubes.

This objection, however, does not appear to be borne out in practice, and in some cases of large modern destructor installations, with fan draught, provision is made for turning on a supply of steam previous to clinkering as an aid to that process.

The question of adding water-gas in combustion is also of importance. The temperature of a destructor cell is usually sufficiently high to decompose the steam and produce water-gas during the passage of the steam through the fuel on the grate.

The clinker removed from the grate bars of a steam blower driven furnace differs essentially from that removed from a cell worked with a fan.

In the former case the underside of a clinker has a hard and vitreous appearance, leaving the surface of the bars with comparative ease.

With a fan draught, unless supplementary steam is used, the labour involved in clinkering is materially increased. The fire bars suffer through the adhesion of the clinker, and the cost of fire bars is excessive.

The introduction of the forced draught in destructor practice, as already stated, led to the utilisation of the waste heat for steam raising for power purposes, and this in its turn has led to the introduction of hot air to the blast, thereby increasing the efficiency of the cell combustion and the steam production in the boilers.

The hot blast is obtained in the Horsfall destructor by driving the air through air boxes placed on the sides of the firing bars in the cell.

In the Meldrum regenerative system the whole volume of hot gases after leaving the boiler is carried through a system of pipes somewhat similar to an ordinary economiser, and in the Heenan destructor a similar system of air heating has been adopted.

The introduction of the hot air blast has been very effective in reducing the quantity of moisture in the refuse, and has rendered practicable the omission of the drying hearth.

In determining upon the type of destructor to be used, the question of what kind of boiler is to be adopted must be considered, and this in turn must largely depend upon the use to which the steam is to be put.

Hitherto the two types of boiler used have been the Lancashire and water-tube boilers, and in a few cases multitubular boilers have been adopted. The latter, however, are not suitable, as, owing to the large quantity of dust to be dealt with, the tubes rapidly become choked, and the effective heating surface is quickly reduced.

Generally speaking, the Lancashire boiler has an advantage over the tubular boiler in steady steaming. The fluctuations in the steam pressure of tubular boilers are found to be very marked.

In addition, the Lancashire boiler provides large steam and water spaces, which are of the highest utility, especially where steam is taken irregularly as in electric lighting. The storage of steam and water under such circumstances is of great value in meeting the fluctuations of steam consumption, and also the variations in the quality and condition of the refuse. They are also simple in construction and economical in upkeep.

On the other hand, tubular boilers have the advantage in the possibility of obtaining a greater amount of heating surface on a given space, and a greater absorption of radiant heat than in the case of the Lancashire boiler, and this feature is one of great importance, especially in dealing with installations placed on sites where land values are high and the area at disposal is restricted. Also, this type of boiler is more easily cleaned and kept free from deposits of dust than the Lancashire type.

Having now considered the points to which attention should be given in selecting a destructor plant, descriptions will be given of the principal types of destructor now on the market.

These may be divided into two classes, namely :—

(1) The slow combustion furnaces.

(2) The high temperature and forced draught furnaces.

In the first division the only representative now in use is the Fryer's destructor with the Jones's fume cremator.

Class I. (Slow Combustion).

Fryer's Destructor with Jones's Fume Cremator.—At Ealing Sewage Works this destructor was developed and improved by Mr. Charles

Jones, M.Inst.C.E., so that he is able to burn the sludge from the precipitation tanks with the aid of the refuse, without previous pressing. Mr. Jones's view is that every town produces sufficient refuse to burn its sewage sludge, and in order to effect this he mixes the sludge with the house refuse. A very few days after the sludge has been pumped into the ash-beds all the draining and drying necessary has taken place, and the material burns readily.

In 1887, with the aid of four cells, the destructors at Ealing dealt with the sewage sludge of a population of 19,000, and the house refuse of 22,000. It was found at first that the smoke from the chimney created a nuisance, in consequence of a certain amount of vapour given off by the fresh fuel passing into the flue without coming into contact with fire. This led to the invention of Jones's fume cremator (Plate LXXXI., p. 796), which consists in the introduction of a "muffle" furnace, intermediate between the cells and the main shaft. Thus everything coming from the cells, burnt or unburnt, has to pass through an intermediate furnace, producing absolute combustion. This cremator is kept going at a cost of 4*s.* 6*d.* per day, the fuel being coke-breeze, and the increased combustion gives additional steam for engine purposes, and, by accelerating the draught, assists very materially the combustion in the cells themselves. The total cost of the destructor, cremator, and chimney was about £2,000.

The report of Professor J. A. Wanklyn on the result of the system at Ealing is as follows:—

"On 9th December, 1887, I paid a visit to the Ealing (Southern) Sewage Works, where all the house refuse and nine-tenths of the sewage from the Ealing district (population, 22,000) is dealt with.

"At these works there is in operation a 4-cell 'Fryer's Destructor,' together with certain adjuncts designed by Mr. C. Jones, the engineer to the Ealing Local Board. 'Jones's Fume Cremator' especially attracted my attention. Readings of the temperature were made at the time as follows:—

In passage from cells to 'Fume Cremator'	610° Fahr.
In 'Fume Cremator'	1,270° „
After leaving 'Fume Cremator'	1,100° „

"At these temperatures, and in presence of the accompanying air, all septic poisons are destroyed, and organic compounds are resolved into carbonic acid, water, and nitrogen gas; only the minutest traces of empyreumatic products could survive and pass away through the shaft into the general atmosphere. No harm to the health of the community is to be expected or feared from these products."

The cells more recently made are 2 feet 3 inches longer than

shown in the plate, and give better results; the single blocks are also considered better than double blocks, back to back, being more readily accessible both at back and front.

The number of cells now in use (1908) is ten, and they consume 24 tons a day from a population of 35,000, in addition to the sewage sludge, from a population of 28,000.

For the destructor itself no machinery is necessary, but if it be desired *to utilise the heat given off to raise steam, a boiler is required.* Other machinery, of course, depends upon the requirements of the works. At Ealing there is a six horse-power engine, which drives the liming machine, clay mixer, works' lift, chain pump, special pump, sludge ram, mortar-mill, etc., and there is steam sufficient to work all the above and additional machinery if required.

A considerable saving is being effected by using the hard clinker as a base for tar paving, thereby causing a saving of 30 per cent.; also on a concrete paving, which can be laid for *3s.* per yard sup., York paving costing *6s. 1d* per yard sup. The finer material from ashpit, which contains a good deal of recalcined lime, makes a splendid mortar mixed with one part of lime to five of ash, and the clinker when ground makes a good mortar with usual proportions. During the years 1899 and 1901, numerous additions were made—further cells were erected on the Ealing model and forced draught was applied to the old cells as well as the new. The mode of dealing with the sludge was also altered owing to it being necessary to utilise space, and sludge presses were erected, and the sludge is now pressed, and the resulting cake taken to the destructors and burnt.

The residuum, or clinker, from the destructors is used in various ways for flag making, road making, concrete walls, and as filtering medium for bacteria beds.

In 1901 a complete installation of concrete slab-paving was laid down, producing 200 slabs per day.

The steam required for driving engines on the works is obtained from two multitubular boilers capable of raising steam for 100 H.P.

Class II. (High Temperature).

Meldrum's Patent "Simplex" Regenerative Refuse Destructor.—This destructor is illustrated by Plates LXXXII., p. 798, and LXXXIII., p. 800, which show the arrangement of an installation on this system erected at Preston in 1901.

The plant consists of four units, each unit containing four fire grates, combustion chamber, Lancashire boiler and regenerator. This installation embodies all essential features in the latest practice of the firm.

The Preston destructor is fed from the front: the refuse is tipped from the tipping floor into a long iron hopper, which forms one side of the firing floor of the four units, the bottom of the hopper being slightly raised above the firing floor, and this enables the fireman to shovel the refuse from the hopper direct into the furnace mouth without depositing it upon the firing floor.

The furnace doors are counterbalanced and are easily raised for charging.

The principle of construction adopted in this type of destructor is to have a single furnace for each unit, but the furnace contains four grates, each of which has its separate firing door, but there are no divisions between the grates, so that there is a continuous fire from end to end of the furnace.

There is a separate ashpit for each grate, and the ashpits are separated by walls, so that the forced draught which is supplied through the ashpit can be cut off or regulated for any grate as required.

The advantage claimed for this arrangement of continuous firing in each furnace is, that when charging operations take place, the products of combustion of the newly-charged grate will pass over and mingle with the products of combustion from other parts of the furnace, and by this means a more even high temperature is maintained than when the fire grates are separated.

The products of combustion pass over a bridge into a combustion chamber where the further mingling of the gases takes place, and the heavy dust from the furnaces settles and is separated from the products of combustion.

After passing through this chamber the products of combustion in the Preston case pass through a Lancashire boiler.

In other installations water-tube boilers have been adopted and are equally applicable.

After passing through the boiler and its settings the products of combustion pass through the regenerator, which consists of a series of tubes, and thence pass to the main flue and through a Green's economiser to a dust chamber at the base of the chimney shaft.

The function of the regenerator is to heat the air required for the forced draught. The air passes through the regenerator outside the tubes through which the products of combustion are passing, and is raised in temperature to some 400° Fahr.

It then passes along a hot air conduit which dips under the combustion chamber and delivers into the ashpits.

The forced draught is supplied either by centrifugal fans or steam jet blowers.

The advantage of a hot air supply for forced draught is great, and

enables refuse of low calorific value when saturated with moisture to be rapidly dried and become quickly ignited.

The cold air inlet to the regenerator can be arranged to ventilate the destructor building and thus obviate the danger of nuisance from the fresh refuse which is stored in the building.

The combustion chamber traps the major portion of the dust passing over the grates, about 75 per cent. being so separated, and this at a point from which it can be conveniently removed from day to day.

Another dust trap is provided in the pit immediately underneath the regenerator, and thus practically the whole of the dust is trapped before reaching the main flue.

The dust rising in the chamber over the grate is of sufficiently high temperature to partially fuse, and adheres to the fire-brick arch in the form of a stalactite, materially adding to its life.

When quantities of butcher's offal, fish, etc., have to be disposed of a special direct charging hopper is provided, for the purpose of introducing such objectionable material direct into the destructor cell without handling.

This hopper is always arranged at the end of the destructor cell furthest from the combustion chamber. Immediately underneath the hopper a hearth is provided level with the grate. The receptacles containing the offal are brought into the works by means of an overhead gantry and are emptied into the hopper, the offal at once falling upon the hearth below.

The gases as distilled from this offal must then pass over the entire grate area from end to end and finally through the combustion chamber, thus securing perfect cremation within the cell.

When dealing with whole carcases of cattle, horses, etc., a simple, direct and convenient means is provided for lowering the carcase whole into the combustion chamber.

The position of the combustion chamber in relation to the destructor furnaces is such that the entire volume of high temperature gases must pass through it, and it is therefore perfectly adapted for the cremation of large carcases.

The temperature maintained in the combustion chamber is, on an average, about 2,100° Fahr.

A diagram of temperatures in a destructor of this make at Nelson shows a maximum temperature of 2,700° Fahr. and a minimum of about 1,700° Fahr.

The Nelson destructor was tested in July, 1903, by the Manchester Steam Users Association; the leading results may be of interest and are quoted here.

The estimated mean temperatures in the combustion chambers on

the two days over which the trial extended were 2,634° Fahr. and 3,326° Fahr.

The refuse consumed was taken from exposed ashpits, and consisted principally of cinders and kitchen refuse.

The water evaporated per lb. of fuel, from and at 212° Fahr. was 1·7 lbs. on the first day and 1·88 lbs. on the second.

A test of the results obtained during a five weeks' run of this destructor from January 2nd to February 4th, 1904, was made by Mr. J. A. Priestley, the Superintendent of the Health Department of the Nelson Corporation.

The furnaces contained 100 square feet of grate area with the same boiler as mentioned in the previous test.

The total weight of refuse destroyed in this period amounted to 781 tons 16 cwt. 2 qrs, which gives an average quantity of 18 tons 12 cwts. 1 qr. per day.

The water evaporated per lb. of refuse from and at 212° Fahr. was 2·12 lbs., the average steam pressure 130 lbs, average temperature of feed water entering boiler 150° Fahr., electricity generated per ton of refuse (average including banking) 42 B.O.T. units, maximum units generated per ton of refuse, 104.

At the Metropolitan Borough of Woolwich, at the Destructor and Electricity Works at Plumstead, a test was carried out on March 29th and 30th, 1904, by the National Boiler and General Insurance Company, the test extending over twenty-four hours.

The destructor in this case was a single unit having four grates, three only being at work at the time of the test, the grate area being 75 square feet. The boiler was by Babcock & Wilcox, with a total heating surface of 827 square feet, and was fitted with Babcock & Wilcox superheater 270 square feet heating surface and a Green's economiser with 1,920 square feet of heating surface.

The total refuse destroyed was 62¼ tons in 24·4 hrs., the weight per hour being 5,805 lbs., the weight of refuse fired per square foot of grate per hour being 77·4 lbs.

The evaporation of water from and at 212° Fahr. per lb. of refuse was 1·92 lbs.

The temperature of the forced draught in ashpit was 392° Fahr., the pressure in ashpit 2 in. of water, temperature of feed of boiler 241° Fahr., steam gauge pressure 195 lbs., temperature of steam into superheater 385·7° Fahr., temperature of steam out of superheater 503° Fahr.

The Preston destructor already referred to is a combined destructor and power station, the power being utilised for tramway purposes.

A test carried out on one unit gave the following results :—

Grate area 100 square feet, Lancashire boiler 30 feet by 8 feet with a heating surface of 986 feet.

Total refuse destroyed in twenty-four hours, 66 tons 19 cwt.

Water evaporated from and at 212° Fahr. per lb. of refuse, 1·7 lbs.

Temperature of combustion chamber, 2,288° Fahr. average and 2,700° Fahr. maximum. Temperature of air on leaving regenerator, 470° Fahr. Temperature of feed to boiler, 222° Fahr.

Steam gauge pressure, 166 lbs. per square inch.

Weight of refuse fired per square foot of grate per hour, 62·5 lbs.

Electrical output per ton of refuse 100·24 B.O.T. units.

The front feed type of destructor was introduced and has been strongly advocated by Messrs. Meldrum Bros., Ltd. A larger number of furnaces on this type are at work on the simplex system than either the top or back-feed types. It is urged that the front-feed type gives better combustion, and consequently more thorough cremation of refuse and higher evaporative efficiency, with somewhat less labour than is obtained with the top or back-feed types. Generally it has been proved that better working results are obtained with this type of feed than any other.

However, the patentees also construct destructor plants on top and back-feed installations to meet the views of their clients and to suit the nature of the refuse to be dealt with, and have several plants of these types in successful working, both in this country and abroad.

Examples of the "Meldrum" simplex type of destructor can be seen at the places named, and also at Sheerness, Watford, Chatham Dockyard, East Ham, Smethwick, Darwen, Holyhead, Ipswich, Stoke-on-Trent, Lancaster, Radcliffe, Hereford, Shipley, Cleckheaton, Weymouth, Eccles and other places.

The "Beaman & Deas" Destructor.*—This destructor is illustrated in Plate LXXXIV., facing p. 802.

The most recent installations on this system are working at Bolton, Bangor, Kingston-on-Thames, Christchurch, N.Z., and Toowoomba, Queensland.

The destructor erected at Hacken Sewage Works, for the Bolton Corporation, is of the most modern design, and embodies all the recent improvements, being specially designed and suitable for burning town's refuse and sewage sludge combined.

The destructor plant consists of eight cells built in pairs side by side.

* The "Beaman & Deas" destructor business and patents were purchased by Messrs. Meldrum Bros., Ltd., in the year 1900.

Each pair of cells has a common combustion chamber, from which the heat generated passes into a main flue, the hot gases from each cell alternately uniting with and consuming the green gases from the other.

From the main flue the heat passes into two branch flues, in each of which is erected a 100 h.p. "Babcock & Wilcox" boiler (each having a heating surface of 1,790 superficial feet), between the water tubes of which it passes and thence travels forward up the chimney. If desired, the heat from the destructor can pass directly into the chimney, but as steam power will invariably be required for a variety of purposes, these occasions will be rare; this arrangement is regulated by dampers provided for the purpose.

The sludge cake, ashpit and street refuse to be burnt are discharged through hoppers on to a hearth leading to a horizontal grate, the bars of which are set very closely together. The ashpit is closed and forced draught is supplied by a fan.

Beyond the grate and opposite the end to which the refuse is fed, is a firebrick chamber wall, and beyond this is the combustion chamber, where, if necessary, the burning gases meet a secondary air supply designed to aid the combustion of any unoxidised products which they may contain.

In the illustration of this type of plant, in Plate LXXXIV., p. 802, it will be seen that an additional grate is provided beyond the combustion chamber for ordinary coal firing. This grate is by no means essential, but for a steam raising plant it is found to be a useful standby to have the ordinary coal fired fittings supplied with the boiler, so that should any shortage of refuse take place the boiler can be worked with coal.

The sludge and refuse about to be burnt, lying upon the drying hearth of the cell, are partially dried by the radiant heat from the refuse burning on the grate, and when pushed forward on to the grate by the stoker do not smother the fire but burn readily.

In normal working, each pair of cells can easily destroy completely 20 tons of mixed house refuse and sludge cake per twenty-four hours, without giving rise to any objectionable smell, smoke, dust, or any other form of nuisance.

The heat generated will evaporate in the boilers about $\frac{3}{4}$ lb. of water per 1 lb. of mixed sludge and refuse. The temperature in the cells, when the forced draught is working, registers 2,000° Fahr., and averages in the combustion chamber 1,500° Fahr.

The following figures of a test carried out at Bangor, on this type of destructor, will be of interest:—

TABLE 128.—RESULTS OF TESTS ON REFUSE DESTRUCTOR.

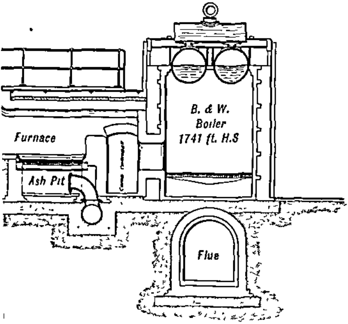
(BOROUGH OF BANGOR.)

14th Dec, 1905.

Particulars.

Time of start	2.45 p.m.		
Time of finish	10.0 p.m.		
Duration of test	7¼ hrs.		
Weather	Fair.		
Type of furnace	B. & D.		
Number of cells or grates	2.		
Effective grate area (per cell 25 square feet)	50.		
Type of boiler	B. & W.		
Heating surface of boiler	1,619 sq. ft.		
Total weight of refuse, including tins	13 tons 5 cwts —29,680 lbs.		
Weight of tins, etc.	5 cwts 1·88% —560 lbs.		
Number of times No. 1 furnace charged	8 times.		
Number of times No 2 furnace charged	9 times		
Average weight of each charge	1,712·9 lbs.		
Weight of refuse burned	13 tons—29,120 lbs.		
Weight of refuse burned per hour	4,016 lbs.		
Weight of refuse burned per square foot of grate per hour	80 32 lbs		
Weight of refuse burned per sq ft of boiler heating surface per hour	2 48 lbs		
Clinker	3 tons 16 cwts —8,512 lbs.		
Proportion of clinker to refuse burned	29 2%		
Combustion chamber, ashpit and flue dust (approx)	8 8%		
Total	38 0%		
Weight of water evaporated	47,000 lbs.		
Weight of water, average per hour (actual)	6,482 lbs.		
Weight of water per lb. of refuse (actual)	1·614 lbs.		
Weight of water from and at 212° Fahr	1 978 lbs.		
Weight of water per square foot of boiler heating surface (actual)	4 lbs.		
Maximum temperature at boiler inlet	About 2,500° Fahr.		
Approximate average temperature at inlet	Over 2,000° Fahr.		
Maximum temperature at boiler outlet	530° Fahr.		
Average temperature at boiler outlet	504 28° Fahr.		
Maximum temperature at chimney base	375° Fahr.		
Average temperature at chimney base	345° Fahr.		
Water entering economiser	46° Fahr.		
Water leaving economiser	151° Fahr.		
Temperature of gases before economiser	504 28° Fahr.		
Temperature of gases after economiser	345 0° Fahr.		
Average ashpit pressure No 1 furnace	$1\frac{11}{64}$ ins.		
Average ashpit pressure No 2 furnace	1 in		
Average on Nos 1 and 2 furnaces	1 086 ins		
Maximum ashpit pressure, No. 1 furnace	2 5 ins		
Maximum ashpit pressure, No. 2 furnace	1 75 ins		
Maximum pull at chimney base	⅜ in.		
Minimum pull at chimney base	¼ in.		
Average pull at chimney base	$\frac{5}{16}$ ins.		
CO^2 in flue gases	CO^2	O	CO
Highest reading	19 9%	9·6%	0%
Lowest reading	10 8%	0 6%	0%
Average reading	17·8%	2 37%	0%

N AND DEAS" REFUSE DESTRUCTOR.



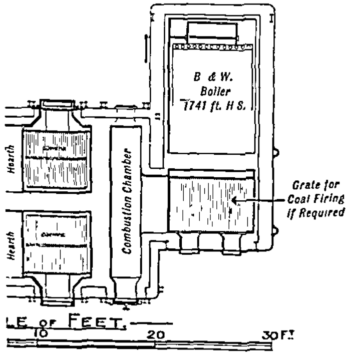


TABLE 123—*continued.*

Particulars.	14th Dec. 1905.
Average temperature of feed-water	46° F.
Average boiler pressure	187·6 lbs.
Electrical output—total B.O.T. units generated during test ...	764 units.
Electrical output—total B.O.T. units generated during test per ton of refuse	58.1 units.

NOTES.—Of the above refuse some 3 tons 17 cwt. were taken from a tip which had been exposed to the weather for months, and was of a wet and very inferior quality.

The actual duration of the test, *i.e.*, until the destructor fire was burned off, was as above, but the boiler continued generating steam until 11.15.

The destructor was started from banked fires, the combustion chamber being quite black; at 11.15 p.m. it was a dull red.

Steam was blowing off during the major portion of the test, and one of the engines was running light to get rid of the surplus steam, otherwise the electrical output would have been considerably higher.

The advantages of this system are embodied in the "Meldrum" simplex top-feed type destructor.

The Horsfall Patent Refuse Furnace.—This destructor consists of a number of cells or furnaces, arranged either in a single row side by side (Fig. 1, Plate LXXXV., p 804) or back to back in one or more blocks (Fig. 2). Each cell is usually 5 feet wide, the grate being 5 feet wide by 6 feet long; thus there are 30 square feet of grate area. Behind the grate is a drying hearth on which the refuse is first deposited and on which it is partially dried before being raked on to the firegrate.

As in the case of Fryer's destructor the refuse is carted up an inclined road at the back and tipped into the feeding bin, for the single row cell, or on to the top of the furnace for the back-to-back type. The fire-bars are placed longitudinally in the furnace, so that no obstruction is caused to the free movement of the firing tools in the working of the furnace, and they are made all in one length for the same reason. The bars are fixed, and the spaces are very narrow.

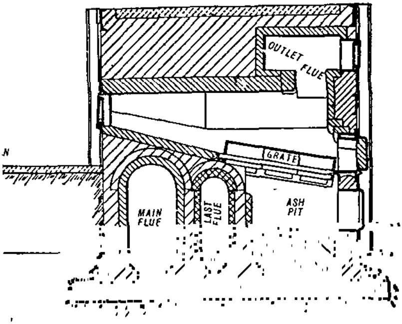
The two types of furnace, viz, the single row type and the back-to-back type, are precisely similar in the general principle on which they work, though the method of feeding is somewhat different. The back-to-back type is preferable, except where there is a difficulty in getting sufficient height of tipping platform to deliver the refuse on the top of the furnaces. The type of furnace to be adopted depends also to some extent upon the number of cells required, as in most cases the single row type is least expensive for any number of cells up to five, and the back-to-back type for larger destructors. On the single row system the

refuse is fed into the furnace through a sliding feeding door at the back of the furnace, as shown in Fig. 1. In this case the work of shovelling in the refuse is a little bit harder than the corresponding work of pushing it down through the feed hole in the back-to-back type. But to compensate for this the work in front of the furnace with fire-rakes is somewhat easier, on account of the possibility of spreading the refuse at the same time as the charging is being done by throwing it on to the required part of the grate with the shovel. In feeding with the back-to-back type no door is used, the bottom of the feeding hole being made in the form of a flat table as shown, so that the feeding hole can be efficiently choked with refuse as soon as the charging operation is complete.

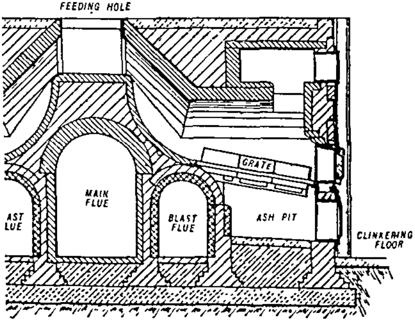
The method of feeding the back-to-back type is very simple. An opening is made through the refuse in the feeding hole by means of the prong used for feeding, and through this opening a large amount of refuse can be introduced with very little labour, the hole being afterwards stopped up with refuse as at first.

The two main principles of the Horsfall destructor are the employment of very high temperatures and the arrangement of the outlet flue in such a manner as to subject the whole of the gases given off from the refuse to the highest temperature of the furnace. To attain these results forced draught is always employed, either by means of steam jet blowers or fans. The forced draught apparatus is generally so arranged as to draw its air supply from the point immediately above the refuse, as delivered on to the deck of the furnace, thus tending to draw off any foul gases which may arise from refuse brought in in a stinking condition. The air is then forced into air-ducts running alongside the main flue and divided therefrom only by a thin wall of firebrick. Thus any heat radiating from the main flue is utilised in warming the blast as it passes through the air-duct. From the air-duct the blast passes by means of suitable valves for its control into cast-iron side-boxes which form the sides of the furnace for about 8 inches above and 8 inches below the fire-grate surface. These cast-iron side-boxes serve a double purpose. In the first place they form the side of the furnace at the part where the abrasion of the wall by the clinker takes place. The substitution of metal for firebrick at this part of the furnace means a heavy saving in repairs, since the clinker cannot adhere to them, and the furnace arch cannot be undermined as has been found to happen with firebrick sides. The second purpose of the side-boxes is to further heat the air for combustion. The delivery openings out of the side-boxes are all placed below the grate and none above it, the air being delivered into the ash-pits under pressure at a temperature of 100° Fahr. It then passes up through the grate-bars, causing fierce combustion, which results in

LL PATENT REFUSE FURNACE



ORSFALL FURNACE—SINGLE ROW



ISFALL FURNACE—BACK TO BACK

a temperature approximating to 2,000° Fahr. in the furnace itself. The subjection of the whole of the gases evolved by the refuse in drying to this high temperature is secured in the Horsfall furnace by placing the outlet openings from the furnace into the flues in the front of the furnace, and immediately over the hottest part of the fire, instead of at the back, as is usual with other types of furnace. The arch of the furnace is continually at a glowing heat, and this position of the outlet therefore causes the gases given off through the drying process to pass along in contact with the hot brickwork, and between it and the hottest part of the fire, before they reach the vent.

The striking effect of this arrangement in the consumption of smoke was noticed by Lord Kelvin and Dr. Archibald Barr, M.Inst.C.E., in their valuable report on the Bradford furnaces, in which they say:—

"The effect of the hot brickwork was well illustrated by observations which we made on the Bradford plant. In watching, through the open clinkering door of a cell, the operation of raking forward a charge on to the grate-bars, dense smoke, as might be expected, was observed; but on looking through a sight hole at the end of the main flue no trace of such smoke could be seen issuing from the discharge end of the cell flue, and only the faintest trace of discharge (probably consisting largely, if not entirely, of steam) was observable at the chimney top. The absence of any hydrocarbons from the products of combustion, as shown by the analyses given below of flue gases collected at Oldham, may be taken as a further indication of the completeness of the destruction of all organic matter in the plant tested."

The "Horsfall" destructor in its original form was developed by Mr. William Horsfall, of Leeds, between the years 1887 and 1893. Its first improvement consisted in the addition of forced draught by means of steam jet blowers to the then existing low temperature destructors. By this means the capacity was raised from 4 to 5 up to 8 or 10 tons per cell per twenty-four hours, and the cost of working correspondingly luced.

Mr. Horsfall's second improvement consisted in the provision of a exhaust flue, whereby the gases and fumes distilled from the charge of refuse were brought through the hottest part of the fire away in contact with a glowing brickwork arch. These ents were applied to the Leeds and other destructors with success.

that the brickwork sides of the furnace were severely the adherence of clinker, and that cast iron protecting not stand the high temperatures produced, Mr. Horsfall his patent side air-box to build into the firebrick wall and having loose plates on the fire side which could

of the cell, the charging door is lifted from its seat and pushed on one side, permitting the movable hopper to descend to the mouth of the hole. The crane continues to lower, and the hinged doors at the bottom of the storage tub thereupon open, and the whole load is permitted to fall directly into the furnace. The refuse falls upon a slope of brickwork which directs it towards the grate, over which it spreads itself naturally, the thickest part being at the rear.

The furnace is provided with grates, having very small openings, and blast is provided by means of high-pressure fans which drive the air through the "Horsfall" new patent wet-bottomed side boxes, by which the air is heated and moistened, thus combining the advantages of the steam blast with the superior economy of the fan.

The charge of refuse being entirely burnt through and converted into a solid clinker, the latter is withdrawn through a very large clinkering door at the front of the cell. The clinkering door carries an inspection door attached to it, through which the trimming of the fire can be accomplished without opening the main door. The clinkering door fits upon planed faces, is counter-balanced, and is held up tightly to its place when closed. Thus during normal working the furnace is entirely gas-tight, the charging door being sealed by means of water and the clinkering door by fitting tightly upon planed faces.

The gases pass into a combustion chamber situated at the back of the furnaces This combustion chamber communicates with the boilers and dust catcher, and so to the chimney. There is also a bye-pass flue direct from the combustion chamber to the chimney, so that in the event of any breakdown of the boilers, or of an excess of steam being generated, the whole or a portion of the gases may be taken by this route instead of through the boilers.

Advantages of the "Horsfall" Tub-Feed Destructor.—1. The objectionable labour involved in the charging of the cells by hand is entirely dispensed with, and the cost of working is exceptionally low.

2. The charging takes place without the liberation of dust and fumes from the surface, the door being only open for a few seconds.

3. The charging door when shut is perfectly gas-tight.

4. The provision of an inclined road or a lift for the carts is unnecessary, and special carts are not needed. They can be ordinary tipping carts of any description.

5. The high blast pressure and other arrangements of the furnace ensure a very high temperature in the cells and combustion chamber.

6. By the use of the new patent wet-bottomed side air-boxes the furnace sides are protected from damage by the clinker, and the air before entering the ashpit is moistened, and at the same time heated to a high temperature, from 400° Fahr. to 500° Fahr. The plates of the

side-boxes which are exposed to the fire are easily replaced, but in practice they have been found to last many years; for example, at Fulham only two sets of front plates for the side-boxes have been required in five years of hard and constant work.

7. The furnaces are entirely lined with specially made firebrick blocks, set in special fireclay cement, and constructed to fit closely to one another. The blocks are sufficiently small to ensure their being thoroughly burnt through in manufacture, and the furnace linings can be most easily replaced when in course of time they become worn out.

8. The arrangement of the combustion chamber is such as to ensure the complete combustion of the noxious gases and to prevent the emission of dust.

9. The forced draught arrangements are provided in each furnace with automatic gear by which the blast is cut off on opening the clinkering doors, thus preventing the outrush of flame and smoke.

The following examples may be given of steam raising results obtained on "Horsfall" destructors :—

TABLE 129.—STEAM RAISING RESULTS OBTAINED ON "HORSFALL" DESTRUCTORS

Date of Erection	Plant.	Refuse burnt per 24 hours	Horse power from refuse	Evaporation per lb of refuse.
		Tons	I H P.	Lb
1900	Pembroke (co Dublin) Electricity Works	18	84	1 2
1901	Stockton on-Tees	23	109	1 22
1902	Salisbury Sewage Works	25	115	1 23
1902	Manchester (Moss Side) Baths, etc ..	60	336	1·25
1903	Bradford, Sunbridge Road Electricity Works	119	652	1·25
1905	Luton Sewage Works	30	180	1·28
1902	Beckenham Electricity Works	32	191	1 34
1901	Accrington Electricity Works	60	308	1·39
1898	Huddersfield Sewage Works	31 2 parts refuse to 1 of sewage sludge.	189	1 42
1900	Fulham Electricity Works, London, S W.	131	680	1·53
1904	Batley Electricity Works..	33	203	1·60
1902	West Hartlepool Electricity Works .	120	650	1 61

Duration of tests, 24 hours to 14 days

It may be noted that in the earlier "Horsfall" destructors the exhaust flues were somewhat complex in construction, but in the later examples this has been entirely modified and the whole of the brickwork, as well

as the ironwork, doors, etc, is of the simplest, most massive and durable character, thus providing against excessive cost of repairs.

Approximate estimates of working costs may be made from the fact that the cost of labour per ton on hand-fired "Horsfall" destructors averages 9*d*. (at English rates of wages), and on tub-feed "Horsfall" destructors 4*d*. to 5*d*. per ton The average cost of maintenance and repairs is from 0·4*d*. to 0·5*d*. per ton. Add to these figures the cost of interest and sinking fund on loan, with a reasonable allowance for supervision, and the total working costs are readily arrived at.

A recent development is in the construction of special small destructors for hospitals, institutions, large country houses, factories, and the like.

Among the cities and towns which have "Horsfall" destructors in use may be mentioned: London (Fulham, Westminster, Finsbury, Chiswick, etc.), Leeds, Sheffield, Oldham, Manchester, Accrington, Blackpool, Folkestone, Leamington, Lowestoft, Ramsgate, Southport, Bradford, West Hartlepool, Newcastle-on-Tyne, Swansea, Bolton, St. Petersburg, Zurich, Brussels, Singapore, Cairo, Hamburg, Pernambuco, Para, Bloemfontein, Durban, Lorenzo-Marques, etc.

The Horsfall Destructor Co. have also made and supplied in connection with many of their plants complete outfits for the crushing and screening of clinker, to form bacterial filter beds and the like, and for the manufacture of mortar, concrete flags, etc., from the bye-products.

Manlove, Alliott & Co.'s Improved Destructor.—A destructor erected by Messrs. Manlove, Alliott & Co., at Cobbe Quarry, Liverpool, is shown in Plate LXXXVI. (p. 810).

The destructor comprises eight cells, each of which consumes 12 to 15 tons of refuse per day; the charging is effected by means of Boulnois & Brodie's patent charging apparatus (Figs. 2 and 3, Plate LXXXVI.), which consists of two trucks for each cell or furnace, each of which is divided into six compartments; the charge contained in one compartment varies from 6 cwt. to 8 cwt., depending on the nature of the refuse. The trucks run on rails over the feed holes; the cover of the cell and the bottom of the compartment of the truck can be simultaneously opened, when the charge of refuse at once drops into the cell, and immediately afterwards the cell and compartment are again closed up; the whole operation is a question of seconds, and there is practically no dust evolved and no smell disengaged. The use of this apparatus involves the following advantages: it provides ample storage for the refuse, and effects at the same time a great saving in the cost of handling it.

Four boilers of the "water-tube type" are employed in connection with the cells, and produce steam at a pressure of 120 lbs. per square inch.

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Four boilers of the "water-tube type" are employed in connection with the cells, and produce steam at a pressure of 120 lbs. per square inch.

TABLE 130.—RESULTS OBTAINED BY A "MANLOVE-ALLIOTT" DESTRUCTOR AT PARTICK.

WORKING TWO NINE-HOURS SHIFTS—EIGHTEEN HOURS WITH SIX HOURS OFF EACH DAY.

1 Date 1905	2 Gallons of water evaporated from refuse	3. B O T units generated from refuse	4 Tons of refuse delivered.			5 B O T. units generated per ton of refuse delivered	6. Lbs. of water per lb of refuse delivered.	After deducting 3 tons per day for banking 7 Units generated per ton of refuse usefully burnt.	8 Lbs of water per lb of refuse usefully burnt	9. Water evaporated in lbs per B O T unit generated.	10. B O T. units generated per ton of refuse at 35 lbs. of water per unit.
			tons	cwts.	qrs.					lbs	
Tuesday, October 24th	16,600	3 933	49	3	0	80 0	1 52	85 1	1·62	42	105 76
Wednesday, October 25th	18,900	4,005	44	9	2	90 2	1 89	96 7	2 04	36 5	120 12
Thursday, October 26th	18,800	4,445	48	17	0	90 9	1 72	96 8	1 83	42	120 31
Friday, October 27th	17,400	4,241	45	12	0	93 0	1·70	99·5	1·82	41	123 66
Saturday, October 28th	17,000	4,157	50	3	2	82 8	1 51	88·1	1 61	40 8	109 5
Monday, October 30th	17,400	3,622	43	7	2	83 6	1 79	89 8	1·92	48	111·6
Tuesday, October 31st	18,900	4,273	48	2	2	88 8	1 75	94·7	1·87	44	117·7
Wednesday, November 1st	16,500	3,976	41	17	2	95·0	1 76	102 1	1 89	41·5	126 89
Totals and Averages	141,500	32,652	371	12	2	88 0	1·70	94 6	1 82	43 5	117 57

In columns 7 and 8 the units and evaporation are given after deducting half a ton per cell per day for banking up fires during the night.

NOTE.—The evaporation for the eight days given above amounts on an average to 43 5 lbs. of water per B O.T. unit. During the eleven days ending September 7th, the average amounted to 35 lbs of water per B O.T. unit generated.

Evaporation includes steam generated for all purposes.

proportion of about 25 per cent. of the refuse consumed. The whole process is carried out without causing any smell, the gases being completely consumed in the cremator and other apparatus.

Torquay Destructor.—The following extract is from a paper by Mr. Henry A. Garrett, A.M.I.C.E., Borough Engineer, Torquay, read before the Institution of Mechanical Engineers :—

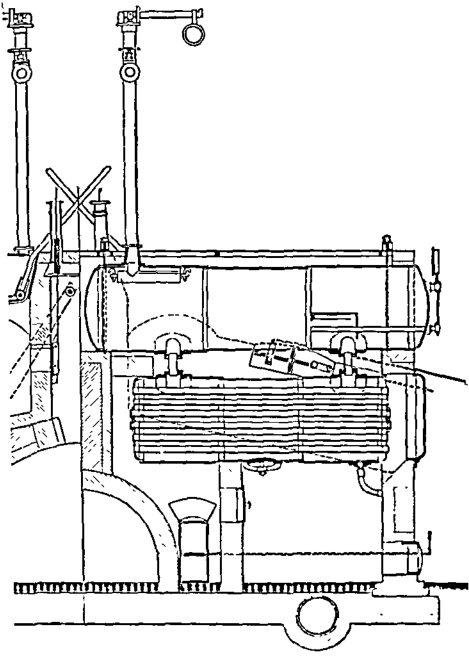
"The destructor is one of Messrs. Goddard, Massey, and Warner's latest types, comprising four cells back to back, having each about 26 superficial feet of fire-bars, of the rocking type upon the wedge-shaped principle. At the back of the fire-bars, directly under the hoppers, is a fire-brick drying hearth with a reverberatory arch built over so as to reverberate the heat upon the newly-fed refuse upon the hearth, thus partially drying it before it reaches the fire. Two multitubular boilers are built in between the cells, the shells of which are 3 ft. diameter by 12 ft. 3 in. long, with steam drum 3 ft. diameter by 9 ft. long, and each is set at a working pressure of 80 lbs., but tested up to 140 lbs. upon the square inch. There are two engines, one horizontal, having a steam cylinder 10 in. by 20 in. stroke, and one vertical engine with steam cylinder 6 in. diameter.

"The horizontal engine is used for driving a heavy mortar mill, having a pan 7 feet diameter, and a Warner's clinker mill, also for driving a dynamo for producing electricity for lighting the works and the district in the immediate vicinity of the destructor. The vertical engine is used for driving the high-pressure fan, air from which is drawn through an 18-inch iron pipe from over the top of the tipping platform, so that the foul air from the refuse may be extracted from the main building and passed under the fire-bars.

"An oil-jet cremator has been provided in the main flue, but this has not yet been made use of, as the temperature in the cells has been found sufficient to consume without nuisance all the refuse delivered to the destructor.

"The circular chimney shaft, constructed of red brick and surmounted by a cast-iron cap, rises to a height of 150 feet above the ground line and rests upon a solid bed of concrete 25 feet 6 inches square, 12 feet thick, carried down to a depth of 19 feet below the ground level. In addition to being used in connection with the destructor, a 15-inch pipe from the main line sewer in the immediate vicinity has been brought to and connected to the cremator chamber. The shaft thus acts as a sewer ventilating column. The shaft is lined with firebrick to a height of 50 feet. At the base of the shaft is constructed a special dust-catching chamber, which prevents the possibility of any dust being carried out at the top of the shaft. A mess-room and bath-room for the men is also provided, together with an office store and weighbridge at the main

ENT "PERFECTUS" DESTROYER.



Scale ½ inch to a foot

Section through one of the Two Boilers

entrance. The whole cost of the works, exclusive of the land, amounted to £6,500."

The following tests on a destructor of this type at Tottenham were made on October 11th, 1905, by Mr. W. H. Prescott, C.E., the engineer to the Urban District Council:—

TABLE 131.

Numbers and type of furnaces	8 Goddard, Massey & Warner, with independent fan to each cell
Number of boilers and positions	4 multitubular, between cells.
Nature of refuse	Dry unscreened ashpit refuse of medium quality.
Weather.	Dry and fine.
Duration of test	Five hours, 11.30 to 4 30
Number of men engaged	*4½ men at 7½d per hour. 1 top man at 7d. per hour. 1 clinker runner at 7d per hour.
* One man was only employed half the time upon working the destructor.	
Total weight of refuse destroyed	22 tons, 10 cwt., 3 qrs, 21 lbs.—50,505 lbs.
Refuse destroyed per square foot firegrate.	31½ lbs or 13½ tons per cell per 24 hours.
Cost of burning only, per ton	9½d
Colour of smoke from shaft	Light brown.
Total quantity of water evaporated ...	4,452 gallons—44,520 lbs
Temperature of feed water entering boilers.	260° Fahr.
Quantity of water evaporated per 1 lb. of refuse.	⅞ lb. with feed water at 260° Fahr.
Steam pressure	145 lbs per square inch all through test.

This destructor has been adopted at Hornsey, Bournemouth, Winchester, Royton, Hyde, Govan, Kensington, Newcastle-on-Tyne, St. George's, Glasgow, Sheffield, Hartlepool, Madras, Berlin, Birkenhead, and other places. It is made by Messrs. Goddard, Massey & Warner, Nottingham

"Heenan & Froude" Destructor.—The "Heenan" destructor (Plate LXXXVIII, p. 814) is one of the back-feed class, fed by shovel.

The apparatus consists essentially of a suitably designed bunker or bin for receiving and storing the refuse as it is delivered from the collecting vehicles, a furnace consisting of two, three, or four cells, a secondary combustion and dust settling chamber, boiler, and regenerator, or air-heater, with either fans or steam jets for promoting the necessary forced draught.

The plant is so arranged that *the refuse is fed into the cells* on one side of the furnace whilst the clinker is withdrawn on the other side, so obviating the chance of any hot clinker and refuse becoming mixed and causing ignition of the refuse outside of the furnaces. Also by keeping the feeding and clinkering floors separate and on opposite sides

of the grates, it is possible to arrange the widths and heights of each floor most conveniently for the work to be carried out therein. This considerably reduced the labour of charging the refuse into the cells as compared with an arrangement whereby the material is charged in from the front on the same side that the clinkering operation is carried out. The grates are arranged on what is known as the intercommunication principle, whereby the products of combustion from all the cells are positively mixed and intermingle in the furnace chamber proper.

The main arch of the roof of the furnace is formed in a specially patented undulating manner, so as to accentuate this essential intermingling of the gases as they proceed towards the secondary combustion chamber, the furnace being, as it should be, the primary or proper combustion chamber.

The several sections of the grate are partially divided so as to minimise the chance of unburnt refuse being thrown out with the clinker. This is very important, as it is most difficult to clinker one section of a grate without withdrawing partly burnt matter from the adjoining sections where the whole grate is of a common level and undivided.

The secondary combustion chamber is an extra safeguard against unburnt gases passing away into the boiler, but it is provided more particularly as a chamber for catching and collecting most of the dust that is carried over from the furnace in the gases; from 75 per cent. to 80 per cent. of the dust so carried over is caught in this chamber. The boiler may either be water tube, Lancashire or Cornish type, but the makers prefer the first-mentioned, as it is the most efficient when gas fired (which is the case with refuse destructor combination). The seatings of water tube boilers also lend themselves specially to the catching of very fine dust, and these deposits may readily be removed—in fact, they may be removed whilst the boiler is at work. This is very different with Lancashire or Cornish type of boiler, where the dust in the flues is not easily got at, and remains red hot for several days after the plant has been closed down. Further, water tube boilers are specially well adapted for carrying the high steam pressure required nowadays by modern steam engine makers.

The regenerator, or air heater, consists of a wrought steel box or nest of wrought steel tubes about 3 inches internal diameter, set in brick setting between the boiler and the main flue for taking the waste products of combustion to the chimney. The hot air for combustion is introduced or forced between the tubes of the heater, either by a centrifugal fan or steam jets, whilst the hot waste products of combustion are passed through the tubes and on to the chimney. In this

way the air is highly heated before it is sent to the furnaces, which is a material aid to combustion and higher thermal efficiency.

It is preferable that the air for this apparatus be taken from the upper portion of the roof of the buildings where it is most likely to be tainted and dust-laden, and if this be done all openings in the building become air inlets, and egress of dust or tainted air from the works is impossible.

It may also be pointed out that the regenerator and its seatings, as described above, form a most efficient catcher of fine dust, and where this apparatus is used no other provision for this purpose is necessary.

The recuperative advantages of the regenerator are essential to the satisfactory and sanitary combustion of any low grade and objectionable fuel or matter, and such apparatus should never be omitted from an arrangement for destroying refuse by fire.

"Heenan" destructors have been erected at the following towns:—Rawtenstall, Blackburn, Gloucester, Northampton, Mansfield, Barrow-in-Furness, Birmingham, Rathmines (Dublin), King's Norton, Lifford (Birmingham), Clydebank, Stalybridge, Stoke Newington (London), and Wimbledon.

TABLE 132.—OFFICIAL TEST OF "HEENAN" PATENT REFUSE DESTRUCTOR, KING'S NORTON

Date of test	Feb. 22nd, 1906.
Duration of test	13·25 hours.
Number of cells under test	3 (1 unit)
Total refuse burnt—25 tons 2 cwt. 2 qrs.	56,280 lbs.
Equivalent rate of burning over 24 hours	45·45 tons
Rate of burning per hour	4,247 lbs.
Rate of burning per hour per square foot of grate area	57 lbs.
Total clinker	14,070 lbs.
Percentage of clinker to total refuse	25 %
Total water evaporated	120,900 lbs.
Average rate of evaporation per hour over whole test	9,125 lbs.
Average temperature feed water	45° Fahr
Average steam pressure	154 lbs.
Water evaporated per pound of refuse (actual)	2·15 lbs.
Equivalent evaporation per lb. of refuse from and at 212° Fahr.	2·63 lbs.
Total steam used by fan engine per hour over whole test in relation to total steam generated	4·78 %.
Total steam used by fan engine per hour, 2 p.m. to 9.45 p.m.	436·7 lbs.
Maximum temperature in combustion chamber	2,131° Fahr.
Minimum temperature of gases in combustion chamber	1,518° Fahr.
Average temperature of gases in combustion chamber	1,826° Fahr.

AVERAGE ANALYSIS.

7 samples taken over 75 % of total time of test

CO_2	O	CO	N
12·1	7·6	0	80·3

Labour cost (2 stokers at 4s. 6d. per shift, 9 hours shift) .. 6·45d. per ton.

Remarks.—Plant under test consisted of: One unit of three cells, total grate area 75 square feet, one water tube boiler, 1,966 square feet heating surface, one superheater 345 square feet heating surface, one fan direct coupled to engine (used to produce forced draught).

Temperatures at two points in combustion chamber were measured and automatically recorded by "Callender" resistance recording pyrometer, also by "Féry" radiation pyrometer, and were found to agree within 100° Fahr.

The analysis of gases is an average of seven samples taken over 75 per cent. of total period of test.

Steam generated was blown off to atmosphere, after having been superheated, through an escape valve set to a lower pressure than safety valves on boiler.

The percentage of steam used on fan engine was obtained by condensing the exhaust over a period of 5·5 hours, the condensed steam being caught in vessels of known capacity.

I hereby certify that this test was carried out under my supervision.

(Signed) AMBROSE W. CROSS, A.M.I.C.E.,
Engineer and Surveyor to the Council.

TABLE 133.—OFFICIAL TEST OF "HEENAN" PATENT REFUSE DESTRUCTOR AT THE INTERCEPTION DEPARTMENT, MONTAGUE STREET, BIRMINGHAM

Date of test	April 26th, 1905.
Duration of test	9½ hours.
Number of cells	4.
Grate area of each cell	25 sq. ft.
Total grate area	100 sq. ft.
Number and type of boiler	1 Lancashire, 28′ 6″ × 8′ 6″.
Total heating surface of boiler	1,000 sq. ft.
Total refuse burnt	26 tons.
Description of refuse (trade and domestic, containing a large percentage of fine dust)	
Rate of burning per hour	6130 5 lbs.
Rate of burning per hour per square foot of grate area	61 3 lbs.
Capacity of plant for 24 hours at above rate of burning	65 6 tons.
Total water evaporated (actual)	76,500 lbs.
Water evaporated per hour	8,052 lbs
Water evaporated per pound of refuse burnt (actual)	1·3 lbs.
Equivalent evaporation from and at 212° Fahr.	1·56 lbs.
Average temperature of feed water	50° Fahr.
Average steam pressure maintained	158 lbs. per sq. inch.
Maximum temperature recorded in combustion chamber ("Chatellier's" thermo-coupled pyrometer, Callender's)	2,213° Fahr.
Minimum temperature recorded in combustion chamber ("Chatellier's" thermo-coupled pyrometer, Callender's)	1,482° Fahr.
Average (¼ hour readings)	1,830° Fahr.
Average temperature of gases entering regenerator	881° Fahr.

Average temperature of gases leaving regenerator...	680° Fahr.
Average temperature of air entering regenerator	65° Fahr.
Average temperature of air leaving regenerator...	365° Fahr.

Average gas analysis (sample taken over entire period of test)—

CO_2	O	CO	N by diff.
12·3 %	7·5%	0	80·2

Snap analysis taken at 6 p.m with all doors closed—

CO_2	O	CO	N by diff.
16·3 %	3·4 %	0	80·3

Total clinker obtained, 6 tons 17 cwt. 1 qr.	15,372 lbs.
Percentage of clinker by weight	26·3

Labour cost of burning during test—

2 men 9½ hours at 7*d.* per hour and one man 9½ hours at 6*d.* per hour . . .. 7·3*d.* per ton.

I hereby certify that this test was conducted under my supervision.

(Signed) WM. HOLT,

Superintendent and Engineer.

"Sterling" Refuse Destructor.—The "Sterling" refuse destructor, Plates LXXXIX. and XC., pp. 818 and 820, may be described as a compound furnace having at least two cells, each with a drying-hearth, a grate and a closed ashpit combined with a combustion chamber placed between the cells. This combustion chamber, through which all the gaseous products of combustion must pass, serves the purpose of a supplementary combustion and dust depositing cell. It is made large enough to admit not only infected mattresses or bedding, but an ox entire. It is, therefore, possible to cremate in this chamber the carcase of an animal which has died of an infectious disease without it being necessary to cut the animal up.

Where more than two cells are required they are arranged in pairs or sets of three on each side of the combustion chamber, making units of two, four, or six cells working into one combustion chamber.

The feeding of this type of destructor is through a specially formed opening at the top, and the material to be destroyed is passed through this opening on to the drying-hearth and grate beneath. The object of the drying-hearth is not to dry the whole of the refuse, but to dry a small portion of refuse in the following manner :—

When a charge of refuse, approximately two tons, is put into the furnace from the refuse storage bin the major part is at once burnt, but a small portion, say about 5 to 10 cwt. lies at its natural angle of rest upon the drying-hearth throughout the time that the rest of the material is being burnt This small collection of refuse as soon as the fire has been clinkered is first of all drawn over the bars before a fresh charge of refuse is put down into the furnace, and this having been dried by the radiant heat of the fire forms a bed of dry, easily

combustible material which is a very great help to the combustion of the green refuse placed upon the top of it by the fresh charge.

The charging-opening, and drying-hearth are as far removed as possible from the exit for the gases to the combustion chamber, in order that any green gases arising through the process of drying the refuse upon the drying-hearth may pass over the hottest part of the fire and be thoroughly consumed. This arrangement, combined with the alternative system of working, so that one cell, at any rate, is always in an incandescent state, is calculated to ensure the destruction of any fumes of a noxious character which might otherwise escape where the cells are worked as separate units.

It is impossible to keep a constant temperature in the cell proper owing to the necessity of opening the door for the purpose of charging and clinkering, and in addition the material when fed to the furnace is in a cool condition, but in this type of destructor by judicious regulation of the charging and clinkering, it is possible to keep one of each pair of furnaces at its maximum temperature so as to consume the comparatively green gases of the other when mixed in the common combustion chamber.

The combustion of refuse in this destructor is aided by forced draught produced by special fan. The makers recommend the fan in preference to the steam blast on the ground that the consumption of steam by the latter is excessive and reduces the steam available for useful purposes. (See percentage in Test later.)

The air for the blast is specially heated in regenerators fixed in the flues at the back of the boilers.

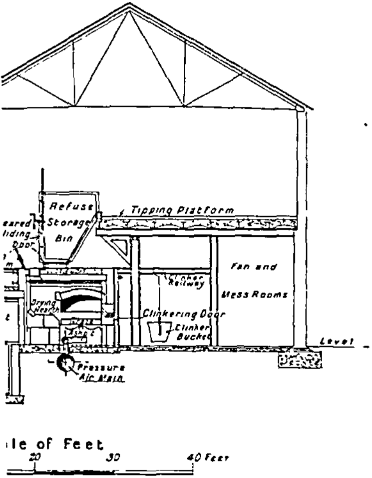
The makers recommend storing the refuse in the carts which collect it. This involves extra carts and stabling for at least one horse at the destructor, but they contend that it is the most cleanly and economical method of dealing with the refuse, which under this system is not disturbed until it is required to be consumed. At the same time, they supply whenever required iron refuse storage shoots, elevated storage bins or floors, and other storing arrangements, but care is taken never to store the refuse on any heated portion of the plant.

The storage of refuse in specially constructed bins is always arranged by the makers so that semi-direct charging can take place, in other words, the opening from the storage bin is adjacent to the charging opening in the crown of the furnace, and consequently the labour required to remove the refuse from the storage bin into the furnace is reduced to a minimum, whilst full control of the amount of refuse put into the furnace at any one time is still maintained.

In either of the furnaces of this type, illustrated in Plates LXXXIX. and XC., pp. 818 and 820, as much refuse as is required to keep the

REFUSE DESTRUCTOR.

ıclıned Roadway Scheme



destructor in full work throughout the night, until fresh loads of refuse come in in the morning, can be stored in a perfectly sanitary manner and can be dealt with at will.

Inclined roads to the tipping platform are preferably provided where the site will allow of it, but where this is impossible or impracticable, transporters, hoists or elevators, according to the requirements of the case, are provided.

The makers of this destructor prefer water tube boilers unless special reasons exist for adopting some other type.

Destructors of this make have been erected at Barry, Aston Manor, Morecambe, Hackney, Bermondsey, Gravesend, Heston-with-Isleworth, Acton, Fredericksberg, Elstree, etc.

The following is a record of a test on the Bermondsey destructor :—

TABLE 131.—TESTS ON STERLING DESTRUCTOR AT BERMONDSEY.

Date	Jan 13th, 1903.
Average temperature in destructor house	45° Fahr.
Character of fuel	Unscreened ashbin refuse
Number of cells used	4.
Grate area per cell	25 sq. ft.
Number of boilers used	2.
Heating surface per boiler	2,010 sq. ft.
Heating surface total	4,020 sq. ft.
Economiser, number of tubes	200
Heating surface	2,000 sq. ft.
Duration of test	7¼ hours
Refuse burned, total	18 16–2–0 tons
Refuse burned, total	42,168 lbs.
Refuse burned per cell per hour	1,454 lbs.
Refuse burned per cell per 24 hours	15·57 tons.
Refuse burned per square foot grate surface per hour	58·16 lbs.
Rate for entire plant of six cells per 24 hours	93·42 tons.
[illegible]	43 %
[illegible] 5¼ hours [illegible]erage of half-hourly readings	93·73° Fahr.
	88·96° Fahr.
Feed water temperature leaving economiser	234·12° Fahr.
Water evaporated, total (actual)	5,980 gals.
Water evaporated, total (actual)	59,800 lbs.
Water evaporated per hour (actual)	8,207 lbs.
Water evaporated per square foot of heating surface of boilers	2·04 lbs.
Water evaporated per square foot of heating surface of boilers and economiser	1·3[illegible] lbs.
Average steam pressure above atmosphere	147·68 lbs.
Water evaporated per pound of refuse (actual)	1·4[illegible] lbs.
Water evaporated per pound of refuse, from and at 212° Fahr.	1·6[illegible]7 lbs.
Percentage above guarantee	6·7 %
Temperature of flue gases behind boilers, average readings	448·5° Fahr.
Fans in use	1

Total units of electricity generated from refuse alone during test, non-condensing engines	688·43
Equivalent total E.H.P. non-condensing engines	922·80
Average units per hour (actual)	91·95
Equivalent E.H.P. per hour	120·70
Maximum units per hour (actual), non-condensing	123·5
Equivalent maximum E.H.P. per hour	165·5
Units generated per ton on refuse destroyed (actual), non-condensing	36·56
Water evaporated per unit, generated, non-condensing	86·86
Note.—Steam was also supplied throughout the test to the Borough Baths, for heating purposes, the quantity not being capable of measurement.	
Total clinker residue	6–7–3 tons.
Percentage of clinker to refuse burnt	33·9 %
Total units used for forced draught during test	48
Percentage used for forced draught during test of actual total electrical units generated	5·81%
Units per ton of refuse for fan	2·54
Taking total water evaporated and allowing the liberal estimate of 40 lbs. steam per K.W. hour, would give the following:—	
Total units generated at 40 lbs. per K.W. hour	1,486
Total E.H.P. equivalent to 40 lbs. per K.W. hour	1,991
Average units generated per hour	201
Average E.H.P. generated per hour	274
Equivalent units generated per ton of refuse	79·00

NOTE.—1. Destructor test started at 8.15 a.m., cells having been lighted up from cold only the night previous.

2. Refuse dealt with was only of average quality, and contained a considerable quantity of fine, dead soil, with some amount of green vegetable matter.

3. The load for the test was provided by the following:—(1) The ordinary demand for light and power; (2) Charging the battery; (3) Heating water for public bath and washhouse.

4. During no part of the test was any coal used, the entire steam raising being done by the destructor from ordinary refuse alone.

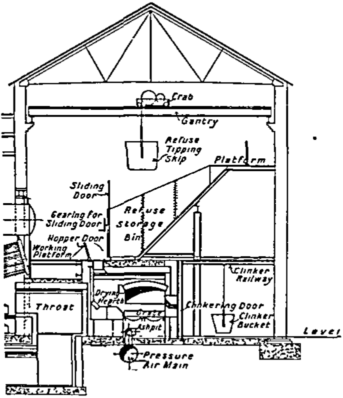
5. When tested for quantity of refuse destroyed merely, the destructor has burned comfortably 20 tons 14 cwt. per cell per twenty-four hours.

STEAM BOILERS.

Utilization of Spare Heat.—Efforts have been made, in many cases successfully, to utilize the spare heat obtained in the process of refuse destruction in a variety of ways, but especially in raising steam for driving machinery and electric lighting. There is some difficulty in reconciling the proper functions of a destructor with the needs of a boiler for the production of steam, as it is essential in any arrangement for this purpose to keep the primary purpose of a destructor well in view, and ensure that its action in this direction is as perfect as possible;

" REFUSE DESTRUCTOR.

tric Travelling Crane Scheme.



ale of Feet.
20 30 40 Feet

when the gases have fully performed their work in the furnace, they may then be applied to a suitable boiler, and the result taken for what it may be found to be worth. If steam power is required for pumping, electric lighting, etc., considerable economy may in many instances be effected by utilizing the surplus power available in this way. The boilers should be placed near enough to the cells to avoid any serious loss of heat by radiation, but not near enough to interfere with the perfect combustion of the gases. Water-tube boilers are apparently the best adapted for the purpose.

Artificial or Forced Draught for.—The object of forcing the draught of steam boilers is to obtain a higher rate of combustion of the fuel per square foot of fire-grate surface than could be obtained by natural draught. The amount of coal that can be burnt per square foot varies with the intensity of the draught from 30 lbs. to 200 lbs. per hour, but for a moderate forced draught, from 35 lbs. to 50 lbs. of coal consumed per hour may be taken as an average. The combustion with a forced draught is more complete than with natural draught; and as the gases are given off at a higher temperature, the efficiency of the boiler is increased.

To develop the same horse power, a smaller grate area and smaller boilers can be utilized than with natural draught.

The fire should not be less than 10 inches thick, and if allowed to be reduced to 7 inches before stoking a loss ensues through the passage of an excessive supply of air, so that as the intensity of the draught is increased so should the thickness of the fire; the space between the crown of the furnace and the top of the fire should be rather more than 10 inches. For forced draught to be economical, the heat generated by the combustion of the fuel should be absorbed as far as possible by the heating surface of the boiler; and for this purpose special arrangements should be made. By the use of artificial draught inferior fuel may be burnt, as it is practicable to arrange a suitable draught, and at the same time to ensure its proper distribution both below and above the fuel in the furnace.

Power Required to Drive Fans for Forcing Combustion.—
Ir. Walter S. Hutton, in his comprehensive work on "Steam Boiler nstruction," states:—"The power required to drive a fan for forcing draught in the furnace of a steam-boiler may be found by the ing formula:—

' = the pressure of the air delivered by the fan in pounds per square foot.

e volume of air at 32° Fahr. in cubic feet used per pound fuel.

"W = the weight of fuel in pounds burnt per square foot of fire-grate surface per minute.

"A = the area of the fire grate in square feet.

"T = the absolute temperature of the air entering the fan in degrees Fahr.

"C = the co-efficient of the efficiency of the fans, which varied in practice from ·2 to ·5.

"Then, the indicated horse-power required to drive a fan =

$$\frac{P \times V \times W \times A \times T}{33000 \times (461^\circ + 32^\circ) \times C}$$

"The pressure of the air in pounds per square foot is found by multiplying the pressure in inches of water by 5·196.

"Example:—Required the indicated horse-power of an engine to drive a fan to deliver air at a temperature of 69° Fahr., at a pressure of 3 inches of water; weight of coal burnt per square foot of fire-grate per hour, 84 lbs.; area of fire-grate 50 square feet; air allowed for combustion 200 cubic feet per pound of coal.

"Thus, the pressure of the air is = 3 inches × 5·196 = 15·588 lbs. per square foot; the coal burnt per square foot of fire-grate per minute is = 84 ÷ 60 = 1·4 lb.: the absolute pressure of the air entering the fan is = 69° + 461° = 530° Fahr.

"The efficiency of the fan may be taken at ·5, and

$$= \frac{15{\cdot}588 \text{ lbs.} \times 200 \times 1{\cdot}4 \text{ lbs.} \times 530^\circ}{33{,}000 \times 493^\circ \times {\cdot}5} = 14{\cdot}21$$

indicated horse-power.

"If 22 indicated horse-power were developed per square foot of fire-grate surface per hour, then the power of the boiler will be = 22 × 50 = 1,100 indicated horse-power, and the power absorbed in driving the fan is = 14·21 × 100 ÷ 1100 = 1·3 per cent. of the total power developed."

The Babcock & Wilcox Boiler. — Considerable attention has been directed to the best means of recuperating the waste heat in destructor gases, and of utilizing it for steam-raising purposes, and the general consensus of opinion is, that the best type of boiler for this work is the patent water-tube boiler manufactured by Messrs. Babcock & Wilcox, Ltd.

The construction of this boiler (figs. 492 and 493, p. 823), may be practically considered as having three distinct parts, namely:

A series of inclined water tubes placed over the furnace, in which the water, being divided into small volumes, is quickly raised to a high temperature and rises, at the front end, through vertical connecting boxes or headers (into which the tubes are expanded).

A horizontal steam and water drum, up to which the water rises from

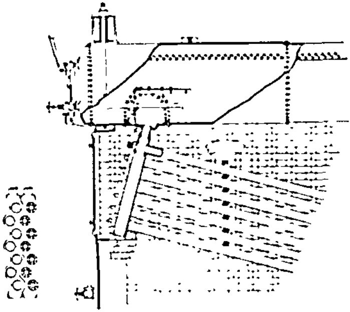


FIG. 492.—The Babcock & Wilcox Patent Water-Tube Boiler. Vertical Section showing details

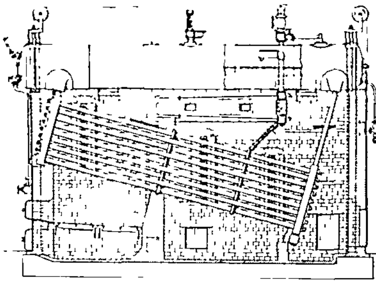


FIG. 493.—The Babcock & Wilcox Patent Water-Tube Boiler. Boiler fitted with Superheater

the headers, and where the steam separates from the water, the remaining body of water returning through the vertical tubes and headers at the back end into the inclined water-tubes, where it is again subjected to the action of the fire, and again passes into the steam and water drum; thus, a continuous and rapid circulation is kept up, and a uniform temperature maintained throughout the boiler.

A mud collector is attached to the lowest point of the inclined water-tubes, into which the matter held in suspension in the water is, to a large extent, precipitated by its specific gravity.

The inclined water-tubes are of steel, and the headers at each end into which they are expanded are sinuous (or staggered) and of mild steel, each header consisting of one zigzag row of tubes, thus forming a complete section. The headers are provided with handholes placed opposite the ends of each tube to permit of cleaning, and, in case of need, the removal of a tube, each handhole being provided with a cap fastened with a wrought steel bolt and clamp and a cap nut, the handhole covers being placed metal to metal. The top ends of each section are connected to the steam and water drum, not directly, but are first expanded into specially designed cross-boxes, which in turn are riveted to and extend from the underside of the drum at each end. The steam and water drum is made of the best selected mild steel double riveted for ordinary purposes; the mud drum is made of mild steel, and is provided with ample facilities for cleaning.

The entire boiler, except the furnace, is suspended by wrought iron slings, from iron girders resting on wrought iron columns, to allow the boiler to expand or contract without straining the brickwork. The boiler and furnace are enclosed in masonry lined with firebrick, the furnace being arranged below the tubes, and firebrick baffles compel the hot gases to pass upwards, then downwards, then upwards again before escaping to the chimney. These hot gases strike the tubes at right angles, thus intercepting the radiant heat from the fuel as effectively as possible; the tubes being zigzagged, the gases are thoroughly broken up as they rise, and, passing into the combustion chamber under the drum, they expand and combine before again passing the second and third time through the tubes and on to the flue; thus complete combustion, rapid steaming, and consequent economy are secured.

The damper for regulating the draught and flow of the gases is placed in the back chamber, whilst doors for cleaning the tubes and removing soot are placed on one side of the brickwork.

A comparison of space is afforded by a new electricity works, where six Lancashire boilers, evaporating 48,000 lbs, of water per hour, are placed beside four Babcock & Wilcox boilers of the above type, evaporating 40,000 lbs. of water per hour under the same conditions.

The ground space occupied by each range of boilers is in the ratio of 10 for Lancashires to $4\frac{1}{2}$ for Babcock & Wilcox boilers.

According to the plans ordinarily adopted, the waste gases from the destructors enter the boilers either at the front or through both side walls, somewhat above the ordinary level of the grate bars, thus enabling auxiliary hand firing to be employed when desired. This is an important consideration, particularly if the destructor plant be worked in connection with an electric light station. When the boilers are arranged in this manner, so that the gases come through both side walls, a destructor cell is placed on either side of the boiler.

By this means a large amount of the total heating surface in the boiler is massed immediately above the entrance of the gases; this ensures not only a higher efficiency, but a far greater evaporative capacity in a given space.

Another point of considerable importance is the very complete arrangements made in the design of the Babcock & Wilcox boiler for a rapid water circulation (whereby all parts of the boiler attain a uniform temperature) and for the free expansion of all the parts. The necessity for free expansion is apparent where boilers have to be fired with any kind of waste heat, the intensity of which may fluctuate rapidly.

An ordinary boiler of the shell type, on account of its rigid construction, and the absence of positive water circulation, must be subjected to heavy racking strains due to unequal expansion, strains which, in the course of a comparatively short time, entail expensive repairs and materially shorten the life of the boiler.

The advantages claimed for the Babcock & Wilcox water-tube boiler are: their safety from disastrous explosion, economy in working and in space occupied, low cost of maintenance, and the fact that all parts of the boiler are readily accessible, and can be inspected during working.

As an indication that these claims are well founded, may be mentioned the fact that Messrs. Babcock & Wilcox, Ltd, alone have over 25,000 boilers, aggregating over two and a half million horse-power, in use, and the following amongst other destructor works have adopted this type:—Birkenhead, Bolton, Cambridge, Canterbury, Leeds, Leyton, Norwich, The Vestry of St. Leonards, Shoreditch (6 boilers), The South London Electric Light and Destructor Works, Wakefield, Warrington, etc., etc.

Some Destructor Works and Results.

Destructor, Southampton.—"All obnoxious matters are collected throughout the borough in specially-constructed, covered, iron tumbril-carts, which go up the inclined roadway approaches to the destructor, and discharge their contents out into the cells. The road-sweepings are discharged into a hopper over the incorporator, and are mixed

with the sludge as required. No obnoxious fumes from the combustion have been perceived. The steam generated in the boilers is employed for driving a pair of engines, of 31·5 indicated H.P., which compress air into two large receivers, whence it passes in a five-inch main to the Town Quay, where it is automatically supplied to nine Shone's ejectors when required for working them. The same boilers also supply steam for the 6-H.P. engine, which actuates an incorporator and elevator, and the engine used in connection with the machinery for the preparation of the horse fodder at the Corporation stables.

"The residue from the continuous day and night combustion consists of about 20 per cent. of good hard clinkers and sharp fine ashes; the clinkers are used for the foundation of roadways and the manufacture of paving-slabs, which have already been used in paving several footpaths of the town, at a cost of 2*s.* 6*d.* per yard; the fine ashes are also employed for making mortar, with which the stables and swimming baths have been erected, and for many other purposes.

"The waste heat from the destructor is also utilized for producing electricity. The engines before referred to drive a dynamo sufficiently powerful to feed either ten arc lamps of 3,000-c.p. each, thirty 1,000-c.p., or two hundred glow lamps of the ordinary 16-c.p. type. At the present time the works are lighted with two 3,000-c.p. and twelve glow lamps; the municipal offices, the church clock opposite, the Hartley Institution, and the Town Hall at the Bar Gate, are also lighted by electricity. For this purpose accumulators have been placed in the basement of the municipal building, to be charged through a cable from the works.

"The initial cost of the destructor, including engine house, inclined roadway, chimney shaft and boiler, and ironwork complete, in 1885, was £3,723, but the addition of four cells and two 60 H.P. boilers has raised the cost to £7,000; and the sewage disposal portion of works about £3,000.

"The annual working expense of the destructors at the present date is as follows.—

TABLE 135.

	Per Week. £	s.	d.	Per Annum. £	s.	d.
Six stokers, £1 10*s.* each	9	0	0	780	0	0
Four feeders, at £1 8*s.* each	5	12	0			
Extra men Sundays, etc	0	8	0			
Maintenance				65	0	0
				£845	0	0

"The maximum quantity of refuse burnt per day of twenty-four hours is 80 tons, and the minimum 50 tons; in addition to which 10 tons of refuse is burnt in the small destructor at the sewage works, Portswood, at an annual cost of £220 11*s.* 4*d.*

"The amount received from the sale of manure and supply of compressed air during the last year was £800.

"The products from the destructor, which include the concrete slabs before referred to, steps for police station, clinkers used for concrete foundations, fine ashes for mortar and foundations for foot-walks, and clinkers sold for new cycle track, represent about another £300.

"To which could also be added the saving for coal required for working the engines.

"As regards the capability of these refuse destructors for supplying power for the machinery, the experience with them at these works extending over fifteen years, proves that a very great saving is effected financially by their use. But unless good stoking is secured, it matters not whatever type of destructor is used, the work will be unsatisfactory both as regards the power obtained and the sanitary disposal of the refuse. This, it must not be forgotten, is before all things the primary function of a refuse destructor, and however well managed a destructor may be, there are times when other fuel must be used if the machinery is to be kept constantly going, as is necessary in sewage works."

Cambridge Destructor and Sewage Pumping Station.—Combined refuse destructors and power plants as patented by Wood and Brodie came into operation in 1896 at Cambridge in connection with the sewage pumping plant. Three units were erected which consisted of six cells or furnaces; between each pair of cells is placed a Babcock & Wilcox Boiler. The products of combustion pass over the hottest part of the fire and enter the combustion chamber, which is immediately under the boiler. An even temperature and consequent steady pressure of steam is claimed for this arrangement. The result of the working of this plant is reported to be most satisfactory. The pumping engines develop 163 h.p., which is employed in lifting the whole of the sewage of the town 52 feet and delivering same through a 24-inch rising main to the sewage farm, which is two miles distant from the pumping station.

Liverpool Combined Destructor and Tramway Generating Stations.—Since the Cambridge plant has been at work others of the same description have been erected in Liverpool where the average daily quantity of refuse burnt amounts to 500 tons. Steam is supplied to the electric generating stations which have been erected adjacent to each destructor plant. It has been found in practice that 100 tons of refuse is consumed each day of 18 hours in a four-unit plant, and steam is raised to provide the power for producing about 8,000 B. of T. units of electricity for the tramway system. The daily output from the destructor plants in Liverpool may be taken at 30,000 to over 40,000 B. of T. units of electricity, the quantity depending upon the quality and quantity of the refuse, which varies with the seasons.

Partick Combined Destructor and Power Station.—A similar plant has been erected at Partick, N.B., which consists of six cells or furnaces with three Babcock & Wilcox boilers of 2,000 square feet H.S. each, and the following figures have been taken from the "log" book kept at the destructor :—

TABLE 136.

Working 18 per day. Fires banked during six hours per day.
3 tons of refuse per day is used for banking fires

Total refuse burned	45 tons.
Total refuse burned in power production................	42 ,,
Total amount of water evaporated from refuse only	20,600 gallons.
Total amount of electricity generated from refuse only	5,357 B. of T. units.
Quantity of water evaporated per lb. of refuse	2·19 lbs.
Quantity of water evaporated B. of T. unit generated	38·63 lbs.
Amount of electricity generated per ton of refuse at 38·63 lbs. of water per unit	128 B of T. units.
Amount of electricity generated per ton of refuse at 35 lbs. of water per B. of T. unit	141·33 B. of T. units.

and from the same source the following gives the result of a full week's working in the month of October, 1908 :—

TABLE 137.

1 Days of the week.	2 Gallons of water evaporated from refuse	3 B of T Units generated from refuse.	4 Tons of refuse delivered.			5 B of T. Units generated per ton of refuse delivered.	6 Lbs. of water per lb of refuse delivered.	After deducting 3 tons per day for banking		9 Water evaporated in lbs. per B. of T. Unit generated.	10 B of T. Units generated per ton of refuse at 35 lbs of water per unit.
			Tns	C.	Qs			7 Units generated per ton of refuse usefully burnt	8 Lbs. of water per lb. of refuse usefully burnt.		
Tuesday ..	16,600	3,933	49	3	0	80·0	1·52	85·1	1·62	42	105·76
Wednesday	18,900	4,005	44	9	2	90·2	1·89	96·7	2·04	36·5	120·12
Thursday	18,800	4,445	48	17	0	90·9	1·72	96·8	1·83	42	120·31
Friday ...	17,400	4,241	45	12	0	93·0	1·70	99·5	1·82	41	123·66
Saturday.	17,000	4,157	50	3	2	82·8	1·51	88·1	1·61	40·8	109·5
Monday	17,400	3,622	43	7	2	83·6	1·79	89·8	1·92	48	111·6
Tuesday	18,900	4,273	48	2	2	88·8	1·75	94·7	1·87	44	117·7
Wednesday	16,500	3,976	41	17	2	95·0	1·76	102·1	1·89	41·5	126·89
	141,500 Total	32,652 Total.	371	12	2 Total.	88·0 Average	1·70 Average	94·6 Average	1·82 Average	43·5 Average.	117·57 Average.

In columns 7 and 8 the units and evaporation are given after deducting half a ton per cell per day for banking up fires during the night.

The evaporation for the eight days given above, amounts on an average to 43·5 lbs. of water per B. of T. unit. During the eleven days ending 7th September, 1908, the average amounted to 35 lbs. of water per B. of T. unit generated.

Evaporation includes steam generated for all purposes.

Combined Electricity and Dust Destruction Undertaking, Borough of Shoreditch.—The novelty in this scheme is the combination of refuse destruction with electric lighting, the arrangements being elaborated in such a manner as to suit each other, and the utilization of Mr. Druitt Halpin's system of feed thermal storage. Electric lifts and motor cars for raising and distributing the refuse throughout the cells are substituted for the usual inclined road and tipping platform, thus effecting a considerable economy in horseflesh. The steam requirements of the electric lighting station at the same time are treated as of secondary importance in comparison with the hygienic manipulation of the refuse.

Shoreditch is a Parliamentary borough in the East Central district of London, with an area of a square mile and a population of 124,000, very densely populated, with the large proportion of 35 per cent. of artizans—the highest percentage in London. It contains in its southern portion (Moorfields ward) a large number of City warehouses and manufactories, forming the recognized centre of the woodwork and furniture industry of London, and offering a splendid field for the sale of electric light and power. The exceptionally large number of public-houses, amounting to 300, and the number of small shops which keep open late at night, make the district one of the largest light-consuming districts in London.

The buildings erected consist of a destructor-house and engine-house, with suitable offices, pump and fan-room, and accumulator-room. The engine-house is 68 feet long and 46 feet wide, and is arranged with the high tension continuous current sets on one side, and the low tension sets and station motor transformers on the other side. A gallery of ample width is provided against one wall of the engine-house to accommodate the three switch-boards.

Off the engine-room is a test-room, in which are erected all the testing instruments, and which, in addition, is used for the calibration of meters.

In order to prevent, as far as possible, vibration from the running of the engines, the whole floor of the engine-house was made a solid mass of concrete, about 10 feet in thickness, and the surface was tiled. The destructor-house is 80 feet square and contains 12 cells,

each having 25 square feet of grate-area, and 6 water-tube boilers, each with 1,300 square feet of heating surface. The cells are charged by means of Boulnois & Brodie's patent charging trucks, and it is possible for three men to keep the whole of the 12 cells charged at regular intervals ; and, moreover, the refuse is never left to ferment or heat on hot brickwork or ironwork, but is kept cool and thoroughly well ventilated by artificial draught. The forced blast in the cells may be procured either by motor-driven fans or by the agency of steam jets.

The gases from the cells pass out of each cell at the side, thence through the boiler tubes and out at the back of the boilers into either of the two main flues leading to the settling chambers and chimney. Whenever required, each boiler may be shut off by means of dampers, entirely free from each or both of its adjacent cells, and may also be fired at all times independently with coal or any other suitable fuel. The cells may also be worked independently of the boilers, but in this latter contingency the gases pass out from the cells at the back and not at the side ; moreover, in the event of refuse not being collected or being deficient, from any cause whatsoever, steam may still be raised in the same manner as is adopted in any other electric lighting boiler-house, viz., by means of coal, fire-grates being provided underneath the boilers for this purpose.

There are 3 motor-driven fans, calculated to deliver each 8,000 cubic feet of air per minute, with a maximum ash-pit pressure of 3-inch water. The chimney is 150 feet high and 7 feet internal diameter at the top, jacketed with fire-brick throughout, and surrounded at the base with a centrifugal dust-separating chamber.

The boilers and thermal storage vessel are designed to work at a pressure of 200 lbs. per square inch, and are supplied with duplicate fittings throughout, to guard against a breakdown. As it is necessary to burn the refuse continuously during the 24 hours, whereas light on a large scale is only used for some 4 to 6 hours out of the 24, it is necessary to adopt a system of heat storage to avoid a waste of valuable steam.

The importance of the thermal storage cylinder is further enhanced by the fact that it acts as a water purifier.

One of the main drawbacks to the use of water-tube boilers has always been overcome by the use of clean or softened water, but if the feed-water be first raised to 350° Fahr. in the thermal storage cylinder, practically all the inorganic salts held in solution in the water will be deposited there, and water free from these impurities will be delivered to the boiler.

The electric work was carried out by the Electric Construction Company of Wolverhampton. The plant at present installed in the generating station consists of 3 E.C.C. generators coupled to Willans'

three-crank engines, each set having an output of 160 kilowatts at about 1,100 volts; and 3 E.C C. low-tension dynamos coupled to Willans' three-crank engines, each set having an output of 70 kilowatts at 165 volts. The speed of the larger sets is 350 revolutions per minute, and the speed of the smaller sets 460 revolutions per minute.

The Willans' engines of both sizes have been specially arranged with hand expansion gear, so that economical results and good governing are obtained when working at any pressure within the wide range of 200 lbs. to 120 lbs. to the square inch; this range of pressure being necessary in order to enable the thermal storage system to be utilized in connection with the scheme.

Results obtained at Shoreditch.—The results of experience gained at Shoreditch may be stated as follows:—

(1) The average calorific value of the London domestic refuse is equivalent to 0·99 lbs. of water per lb. of refuse burnt; this is, however, subject to some deduction if the whole year's working is considered, as it is not always practicable to store or utilize the whole of the heat generated

(2) The cost of destruction of refuse is 2*s.* 5*d.* per ton, which is less than the cost of barging away.

(3) The arrangement of one boiler to two furnaces, as at Shoreditch, may be relied on to evaporate 2,888 lbs. of water per hour from and at a temperature of 212° Fahr. at a pressure of 200 lbs. per square inch, using refuse as fuel.

(4) It is estimated, from the data thus made available, that the total amount of power which could be made available in London by burning the whole of the refuse in properly constructed furnaces would amount to about 133,000,000 B.H.P. hours.

The supply of refuse has been found to be very irregular, so much so that it has been necessary to provide a large rectangular iron storage-bin under the tipping platforms to hold about 60 tons of refuse. The delivery takes place between 9 a.m. and 5 p.m., and averages 84 tons per day, though as much as 140 tons have been received in one day.

The tip-trucks and lifts, which are worked by electricity, have been found to be very satisfactory, although they absorb as much as 0·52 kilowatt-hours per ton, principally in the operation of lifting the refuse to the top platform.

It is very necessary in designing works of this nature, where an inclined roadway is not available, to provide ample facilities for lifting the refuse so as to avoid a loss of time from keeping the dust-vans waiting.

The full efficiency of coal fires when used in conjunction with refuse is not obtained, as a large amount of cold air is unavoidably admitted

in the process of clinkering the refuse furnaces; the shavings and chips which form a large percentage of the Shoreditch refuse not found to give such good results as fuel of a heavier nature. Th due to a great extent to its burning away as fast as it is put in, an the time cold air is being admitted to the furnace. The residue amc to 32·8 per cent. The clinker and fine ash from the destructor are for making mortar concrete and artificial paving stones; the latter made with $2\frac{1}{2}$ parts ground clinker to one of Portland cement f ground, and subjected to a pressure of $1\frac{1}{4}$ tons to the square inch.

After the plant had been in use for some time it was found that temperature of the flue gases at the base of the chimney reach maximum of 700° Fahr. It was then decided to introduce a G economiser, and it was arranged for the boiler-feed to be forced thr it into the thermal storage vessel; the feed is thus heated in pas through the economiser to a temperature of from 200° to 250° F This plan has been adopted since October, 1898, and has been foun the greatest value, as it obviates the tendency to water-hammering w formerly obtained and enables the boiler-feed to be readily and corr adjusted.

The Cambridge, Liverpool, Partick and Shoreditch plants were erected by Messrs. Manlove, Alliott & Co., Ltd., Nottingham, similar plants are also at work at Wolverhampton, Nottingham, Y Winchester, Stafford, Stepney, Rhyl, Loughborough, Leicester other places.

Disposal of Residuals.

The residual produced by refuse destruction consists of clinker, this is utilized in various methods. The first process is to elimi the old tins and other metal objects which are picked out by h and the remaining material then depends largely for its value upon quality.

This is governed principally by the temperature at which the dest tor has been working and the length of time to which the refuse been subjected to that temperature. A good, hard, vitreous clin cannot be produced in the old low-temperature destructors and is c possible from the modern furnaces.

In addition to having a furnace capable of working at a high temp ture and allowing the material to be in contact with that temperat for a sufficient time to fuse and vitrify all the inorganic matter is necessary that the charging and working of the cells shall be c ducted upon a regular system and that the fires shall be worked wit *uniform thickness of material* upon the grate bars. Otherwise the l furnace will not give satisfactory results and a poor clinker will

produced which is worthless and may involve expense to get rid of, instead of being a source of revenue.

A good hard clinker is always useful in the suburbs of towns for road foundations, for coating newly-formed streets which are not yet paved and flagged, for surfacing semi-rural footpaths and the like.

Clinker can also be used for filling up low places and for tipping on land where ordinary refuse would be objectionable, whereas the clinker is perfectly innocuous and inoffensive.

Early on in the history of destructors it was found that the clinker when ground and mixed with lime produced excellent mortar, large quantities of which have been made and sold to builders in Leeds, Bradford, and other towns since destructors were first introduced.

The manufacture of paving flags for footpaths is another of the uses to which the clinker is put, the town of Brighton being one of the leaders in this movement, and flag-making plants are now in use in numerous towns, including Liverpool, Birmingham, Sheffield, Bradford, Leicester, Oldham, etc

The clinker is ground up and mixed with Portland cement in the proportion of two to one, and the flags are then made in a moulding machine operated by hydraulic power. Messrs. Fielding & Platt are the makers of a machine of this character, which gives excellent results, and with which paving flags $2\frac{1}{2}$ inches thick can be produced at a cost of from 1*s*. 6*d*. to 1*s*. 9*d*. per square yard.

In some cases the wearing surface of the flag is fortified with granite chippings to increase its life, but this can only be done at an additional cost of something like 6*d*. to 8*d*. per square yard.

With the introduction of bacterial processes of sewage purification a large demand has arisen for the best and hardest clinker as a filtering medium for the bacteria beds, and excellent results are produced by the use of this material, provided it is thoroughly hard and vitreous and has removed from it as much dust and small particles as possible.

Where the destructor is situated near the bacteria beds its value is further enhanced by reducing the item for cartage.

In Liverpool Mr. J. A. Brodie, M.I.C E, the city engineer, has utilized crushed clinker with cement for building concrete cottages in connection with the clearing of insanitary areas. The concrete is filled into moulds to form huge slabs representing a complete wall, floor or roof of a house, the openings for doors, windows, fireplaces, etc., being formed in the slabs, which are dovetailed together and jointed with cement mortar. The balconies, stairs and chimneys are all constructed with the same material, and even the site itself is levelled with clinker.

Brickmaking is another means of utilizing destructor clinker, and a

complete plant installed by the Nelson Corporation in 1907 is produ good serviceable bricks

The plant consists of :—

A ball mill for lime grinding.

A 9 feet perforated grinding mill for clinker grinding.

A screen for screening the clinker.

A patent hydrating mixer.

Brickwork silos.

A final mixer.

An "Emperor" press.

A hardening chamber to hold 7,000 bricks.

In addition there are the necessary waggons, elevators and plan the distribution of the materials and power.

The plant is driven by electrical power obtained from the adjoi electricity station (the steam for which is partly supplied from waste heat of the destructor).

The plant is divided into two sections driven by separate mo For the grinding portion a motor of 40 H.P. is provided, and for final mixing and brickmaking a motor of 25 H.P. is provided. average power required is, for the grinding, 28 H.P. and for the mixing and brickmaking 12 H.P.

A typical analysis of the clinker produced at the Nelson Corpora Destructor Works is as follows :

TABLE 138.—ANALYSIS.

Silica	40·6	per cent.
Lime	11·2	"
Alumina	18·5	"
Ferric oxide	22·8	"
Magnesia, manganese and alkalies	6·9	"

and at the same time the whole is thoroughly mixed and subjected to a special boiling process in a patent mixer specially designed for this purpose, with the result that the mixture leaves the machine in a wet state and at a high temperature; it then falls into silos or storage hoppers, where it rests and matures. The period required for maturing varies from twelve up to as high as thirty-six hours, depending upon the nature of the clinker and the lime being treated.

The object of this maturing is to ensure slaking of the added lime, and also the lime compounds found in the clinker. For instance, in the analysis of the clinker given above, it will be seen that it contains 11·2 per cent. of lime, which, in passing through the destructor, is not only turned into quicklime, but is also partly combined with the other constituent substances of the clinker, forming silicates and aluminates of lime. These substances do not slake readily, and unless the clinker is treated to slake these compounds it is impossible to make sound bricks.

The maturing hoppers are built of brick or of sheet steel with a suitable discharging apparatus in the base. Two are required, so that whilst one is being filled the mixture in the other is being discharged and made into bricks.

After maturing, the material is ready for the final process of being made into bricks. To this end it is drawn from the silo and passed automatically to a mixer, where, if required, additional moisture is added, and then to the brick press, where it is compressed into bricks under enormous pressure, each brick receiving from 100 to 150 tons pressure upon it, with the result that on coming from the press, although green, it will stand handling and considerable rough usage.

The press used is Messrs. Sutcliffe, Speakman and Co's "Emperor" press, which is the result of practical experience in the special design and construction of presses for various materials.

As the bricks leave the press they are stacked on waggons and are then wheeled into the indurators or hardening chambers, where they are subjected to the action of steam at a pressure of 125 lbs. per square inch. It requires eight to ten hours of this treatment to thoroughly harden and finish the bricks. After withdrawal from the chamber they are hard and fit for immediate use.

The hardening chamber consists of a steel cylindrical vessel six feet diameter and from thirty-five feet up to seventy feet in length, one end being removable and held in place by massive steel bolts. In some cases this removable end is merely slung from a small crane or set of chain blocks, but preferably it is hinged to the chamber and provided with a balance weight, making it easy to open and close.

It will be seen from the above description that the whole period required for manufacture, from the taking of the raw material to the

delivery of bricks ready for use, does not exceed thirty to forty-eight hours; when this is compared with the lengthy process required for the making of ordinary clay bricks, which usually takes three weeks, it will be apparent that this system offers many advantages.

The hardening of these bricks is brought about by almost identically the same chemical changes that take place in the hardening of cement; some cements of the best quality can be hardened quickly by steam as described above, but generally they contain unslaked lime compounds which prevent the hardening being done in this rapid manner, hence the slow process of ageing is adopted. These unslaked lime particles then expand so gently as not to interfere with the solidity of the concrete.

If we compare the chemical composition of these bricks with the chemical composition of a concrete made with cement and the same clinker we shall get the following:—

TABLE 139.—COMPARISON OF ANALYSIS OF LIME BRICKS AND CEMENT CONCRETE.

Clinker and lime bricks made with about 8½ per cent. of lime	per cent.	Clinker and cement concrete made from 1 cement and 5 clinker.	per cent.
Lime	17·0	Lime	16·8
Silica	32·5	Silica	32·2
Alumina	14·8	Alumina	14·1
Ferric oxide	18·2	Ferric oxide	16·8
Magnesia and alkalies	5·5	Magnesia and alkalies	5·8
Water in combination	*12·0*	*Water in combination*	*14·3*
	100·0		100·0

In the above, which is a calculation from the known ingredients, a cement is taken of an analysis as below:—

Lime	62·04	per cent.
Silica	22·04	„
Alumina	6·45	„
Ferric oxide	3·41	„
Sundries	6·00	„
	99·94	per cent.

If the two be compared it will be seen that they are almost identical. In both cases there are the ingredients which give the hardening due to the slow crystallising of the cement, the only difference being that whereas one is due to age the other is brought about by steam.

During the steaming operation nothing is added or taken away from the bricks, the steam merely acting as a heating agent, permitting the bricks to be raised to a temperature of about 300° Fahr., and at the same time retain their moisture. If the steam were at a lower pressure the required heat could not be obtained, whilst if heat were used without steam, the water would be driven out, and the bricks would not become hard.

The hardening is a crystallising of a compound consisting of lime, silica, alumina, and water; without the water, hardening cannot take place, and because of this fact the many attempts to use superheated steam at low pressure have failed.

In quality the bricks closely imitate a Staffordshire blue brick of fair quality, except that they in general absorb a slightly higher percentage of water. They are blue or slate colour, and a test made by Messrs. Kircaldy gave the following :—

TABLE 140.—COMPRESSIVE STRENGTH.

Description	Dimensions	Base.	Stress in Pounds.		
			Cracked Slightly.	Cracked Freely	Crushed
	Inches.	Sq. in			
Composition brick, no recess, made from destructor clinker and 6% of lime.	2.77 × 9.00 × 4.36	39.24	222,000	259,800	262,000
	2.95 × 9.02 × 4.40	39.69	199,900	230,800	248,000
	2.80 × 9.00 × 4.34	39.06	154,600	222,700	224,700
	2.63 × 9.02 × 4.36	39.33	150,900	206,000	206,000
	2.62 × 9.02 × 4.36	39.33	134,500	201,700	201,700
	2.80 × 9.00 × 4.36	39.24	130,600	159,000	159,000
	Mean	39.31	165,417	213,833	217,067
	Lbs per sq. in	—	4208.0	5440.0	5522.0
	Tons per sq. ft.	—	270.6	349.8	355.1

TEST FOR ABSORPTION

Description.	Before Immersion	After 24 hours' Immersion	Difference	Absorption	
	Lbs	Lbs	Lbs	Per Cent	
Composition brick, grey, no recess	9.330	9.679	0.367	3.93	6.72
Composition brick, grey, no recess	8.510	9.273	0.763	8.97	
Composition brick, grey, recessed one side.	8.573	9.195	0.622	7.26	

The quantity of clinker produced is only sufficient to enable about 18,000 to 21,000 bricks being made per week, hence it follows that the plant is not run continuously. It is run alternatively: on Fridays, Tuesdays, and Wednesdays, the clinker is being ground, mixed and deposited in the silos, whilst the bricks are made up on Saturdays, Mondays, and Thursdays, the same set of men operating both sections of the plant. The labour required is very small, due to the labour-saving devices provided. Three men are sufficient to look after the whole installation.

The steaming of the bricks is effected during the night, and is done by steam from the destructor boiler, which would otherwise be wasted, as it only serves the electrical works on the day shifts.

It will thus be seen that the cost of working is very low. Making these 18,000 bricks per week requires the wages of three men, and the cost of $1\frac{1}{2}$ tons of lime, *plus* the wear and tear of machinery, which is only a small item. The total cost of the bricks is stated to be 16*s.* per 1,000 inclusive of capital charges.

The cost of the plant was about £3,000, and in connection with it there is a solder recovery plant and a tin-baling press. The solder extractor is a furnace in which the disused tins which come to the refuse destructor are placed. Solder is extracted to the extent of 50 lb. per ton of metal used, and there is a ready market for it at 8*d.* per lb. After the solder has been extracted the tins are placed in a large press and pressed into bales, which are disposed of at the rate of 12*s.* 6*d.* per ton.

Utilization of Steam.—The steam produced by the destruction of refuse is utilized in connection with baths, wash-houses, electricity works, sewage works, waterworks and other municipal enterprises.

The records of tests which have already been given indicate the quantity of steam which can be raised from the destruction of refuse, but it must be borne in mind that these figures are obtained under trial conditions and must be discounted when considering the amount of power available under ordinary working conditions.

As an indication of what can be done in practice the Table on page 839, reproduced from "Refuse Disposal and Power Production" (W. F. Goodrich), gives a comparative statement showing the number of electrical units generated per ton of refuse destroyed at 20 combined electricity and destructor works.

It is beyond the scope of the present work to attempt to describe the appliances necessray to utilize the steam, and the following Table is merely an indication of the amount of power which can be obtained from the consumption of a given quantity of refuse.

TABLE 141.—COMPARATIVE STATEMENT SHOWING THE NUMBER OF ELECTRICAL UNITS GENERATED PER TON OF REFUSE DESTROYED AT 20 COMBINED ELECTRICITY AND DESTRUCTOR WORKS

Town.	Make of Destructor	Type of Destructor	Type of Boiler	Average number of Units generated per ton of Refuse destroyed	Average weight of Refuse destroyed daily in tons
Accrington	Horsfall	Top fed	Lancashire	25 0	60 0
Bangor ..	Meldrum	"	Hornsby	20·0	9 0
Cleckheaton	"	Hand fed	Lancashire	35 0	12 0
Colne	"	Top fed	Babcock	20 0	18 0
*Darwen ..	"	Hand fed	Lancashire	33 0	35 0
*Fulham ...	Horsfall	Top fed	Babcock	26 6	100 0
Gloucester	Heenan	Back fed	"	35 0	25 0
Grays ...	Meldrum	Hand fed	Lancashire	33 0	8 0
Liverpool ..	Manlove	B & B	Babcock	29 5	97 0
Llandudno	Meldrum	Top fed	"	32 0	15 0
Nelson ...	"	Hand fed	Lancashire	40 0	30 0
†Partick	Manlove	"	Babcock	27 0	42 0
Rhyl	"	"	"	15·0	16 0
*St. Helens	Meldrum	"	"	37 3	32 0
‡Shipley	"	"	Lancashire	37 8	25 0
*Shoreditch	Manlove	B. & B.	Babcock	20 0	80 0
Stepney .	"	Top fed	"	32 0	165·0
Warrington	Meldrum	"	"	80 0	50 0
§Wimbledon	"	"	"	45 0	54 0
Wrexham	"	Hand fed	Lancashire	38 0	35 0

* Average for one year † Average for three months
‡ Average for one month § Two-thirds refuse, one-third sludge

In the well-known case of Ealing, Mr. Charles Jones, M.I.C.E., has for years been destroying his town's refuse in conjunction with the sludge produced at the sewage disposal works, and has also had a margin of steam for power purposes.

At Hereford and other places all the steam power necessary for operating the sewage works is obtained from the destructor, which disposes of a part only of the city's refuse.

The Southampton destructor is also used in connection with the sewage works and is referred to in the description of those works, p. 825 *et seq.*

At Norwich the destructor provides the necessary steam for working the engines and air compressor which are installed in connection with "Shone's" ejectors for lifting the sewage of the low parts of the city, and power is also provided for working the machinery of the corporation's stables and depôt.

As an adjunct to waterworks a destructor is not perhaps as suitable as in some other connections, as sentiment dictates the inadvisability of taking objectionable matter anywhere in the neighbourhood of the water supply of a town. In most cases the pumping stations in connection with

water supply systems are situated at too great a distance from the town to enable the refuse to be economically carted to it and there destroyed.

In some few instances, however, when pumping to a special high level from a central position in the town, it may be advisable for destructors to be established so as to utilize the steam for power purposes.

At Hunstanton in Norfolk a destructor is used in conjunction with the waterworks, although the cost of cartage is somewhat excessive, but is not greater than it would be for ordinary fuel.

Cost of Labour.—The cost of labour necessary at destructors is a most important factor for consideration. It must, however, be clearly pointed out that it is not the only test applicable to the relative merits of rival makes.

Capital cost may also be of importance, especially where a difficult site has to be dealt with. The cost of repairs and depreciation, perfect combustion, and absence of nuisance are essential matters, and from an economical point of view steam raising and good vitreous clinker are equally as important as low labour costs.

Again, the difference in the rate of wages paid in different parts of the country must be taken into consideration in determining the value of a figure for the cost of labour. The variation in the rate paid per hour is greater than may be supposed, ranging from *4d.* per hour up to *8d.* per hour.

It is obvious, therefore, that before one can form any opinion as to whether or not a destructor is worked with a small amount of labour, one must know the rate of wages paid in the district.

Again, the amount of mechanical power used in connection with the charging process must be taken into consideration, as one of the chief objects of mechanical installations is to reduce the amount of labour involved. It must be, however, admitted that this result does not always follow.

The cost of labour may vary from *7d.* to *2s.* per ton, the latter figure, however, being exceptionally high.

For general averages the following figures may be considered approximate :—

For top feed systems	1*s.* 2*d.* per ton.
Mechanical charging systems	1*s.* 3*d.* ,,
Front hand fed systems	11*d.* ,,
Back hand fed systems	1*s.* 2*d.* ,,

Taken all round, a better test than the cost per ton of refuse burnt is the weight of refuse which can be handled per man in a shift of 8 or 12 hours, as the case may be.

The following remarks by a well-known engineer, who has been engaged in designing refuse destructors for over 25 years, are worthy of consideration by those about to embark on this subject.

Nowadays, too many of those who have to do with the erection of refuse destructors are inclined to think, or at least to act, as if they thought that one ton of refuse must be as like to every other ton of refuse as one pea usually is to another out of the same pod.

They ask for a guaranteed evaporation per pound of refuse and a guaranteed percentage of clinker, while they are quite unable to tell whether their refuse will contain 35 per cent. of combustible matter or 55 per cent., whether it will show on analysis 25 per cent. of mineral matter or 45 per cent., or at any rate are unwilling to give any guarantees on the subject; and they desire to retain the right to ask for results guaranteed, no matter how much the quality of the refuse may deteriorate, as it may readily do. It would be well to remember that no guarantees in the world will enable a furnace to produce more heat from a ton of refuse than its combustible contents can generate, mixed as they are with incombustible matter, and in like manner no guarantees will ensure 26 per cent. only of clinker and ashes when the refuse contains 33 per cent. of incombustible matter.

Any requests for guarantees as to results to be obtained with refuse of unknown and varying qualities is to ask for a guess—and in such guessing the prudent and cautious are very heavily handicapped, while the sanguine and over-confident and the reckless are given every advantage, especially if they are able afterwards to plead, in case the work done falls short of their guarantees, that the authorities have supplied refuse which could not possibly, even theoretically, be made to fulfil such guarantees, and that the authorities themselves ought to be well aware of this.

If any impossible guarantee be accepted a manifest injury is done to the more prudent or better informed person who would only give a possible one; while when the impossible guarantee proves to be impossible, the authority or engineer is put into a position almost as difficult and unpleasant as that of the contractor.

It may not be out of place to quote, in concluding, the views recently expressed by Mr. Stromeyer at a meeting of engineers. He is reported to have said that—

The calorific efficiency was not necessarily proportionate to the amount of carbon in the fuel. The efficiency was pulled down by the presence of incombustible matter, beyond and in addition to the diluting effect of such matter in the fuel. Supposing that, with pure coal, water cost, say, one shilling per ton to evaporate, then with a coal containing 10 per cent. of earthy matter the cost would be 1·5s., with 20 per cent. of earthy matter 2·25s., and with 30 per cent. 4·25s. In other words, coal containing 30 per cent. of incombustible refuse was only worth one-fourth as much as pure coal.

CHAPTER XXII.

CONSTRUCTION OF CHIMNEY SHAFTS FOR DESTRUCTORS.

Object of—The object for which a chimney shaft is built is, in the first place, to produce a draught through the fuel or on the fire-grate, to ensure the combustion of a specified amount in a given time; in the second place, its height should be sufficient to carry off the products of combustion to such a level above the neighbourhood as to avoid creating a nuisance. This particularly applies to chimney shafts for destructors.

The draught in the chimney is caused by the difference in weight of the heated gases inside the chimney and the corresponding column of air outside the chimney. This difference in weight is principally due to the expansion of the gases passing up the chimney, produced by heat; they are thus considerably lighter than the external air, which therefore seeks to penetrate through every available opening, both below and above the fire-grate. This produces a velocity of efflux, after making a deduction for friction, due to the difference in weight of the two columns

The draught in a chimney is thus obtained by a considerable expenditure of fuel, amounting to as much as from 20 to 30 per cent. of the coal burnt.

Where inferior fuel is employed, as in the case of destructors, increased draught is necessary. This involves an increased height of chimney shaft.

Dimensions of Chimneys—General Rules.*—"The outside diameter at the ground level should not be less than one-tenth the height, unless it is supported by some other structure.

"The batter varies from 1 in 60 to 1 in 10; 1 in 24 is very common. Or the batter should be from $\frac{1}{16}$ to $\frac{1}{4}$ inch to the foot on each side.

"The thickness of brickwork is generally one brick (8 or 9 inches) for

* These particulars are extracted from "*The Engineer's Year-Book of Formulæ, Rules, Tables, Data, and Memoranda,*" by H. R. Kempe, M.Inst.C.E., M.I.E.E., one of the most generally useful of reference books for practising engineers.

25 feet from the top, increasing one half brick (4 to $4\frac{1}{2}$ inches) for each 25 feet from the top downwards. If the inside diameter exceeds 5 feet, the top height should be one and a half brick thick, and if under 3 feet it may be one-half brick thick for 10 feet.

"Generally, a much less height than 100 feet cannot be recommended for boiler chimneys, as the lower grades of fuel cannot be burned as they should be, with a shorter chimney. Tall chimneys should always stand alone; for if connected with the rest of the buildings, the increased settlement due to their height causes rupture in the masonry. The distance from the furnace to the shaft should not exceed two-thirds the height of the shaft, and the latter should be built and allowed to settle before the connecting-flue is made.

"The circular form of chimney is best, as, with the same quantity of material, it covers a greater area, and is therefore more stable, and the effect of wind upon it is much less. In any case, the flue should be circular; it can hardly be too large, as it can always be reduced by dampers. It should be built with a detached skin of fire-brick for a certain distance up, increasing in proportion to the heat of the vapours carried off, and separated from the main shaft by an air space.

"The caps are intended to tie the head of the chimney together, but projecting caps catch the wind, and increase the oscillation; a dangerous chimney has been saved by removing the cap.

"The scaffolding used for building a chimney should be so arranged, that it does not prevent the chimney from settling.

"The intensity of draught required varies with the kind and condition of the fuel and the thickness of the fires. Wood requires the least, and fine coal or slack the most. To burn anthracite slack to advantage, a draught of $1\frac{1}{2}$ inch of water is necessary, which can be attained by a well-proportioned chimney 175 feet high.

"The effective area of a chimney for a given power varies inversely as the square root of the height. The actual area in practice should be greater, because of retardation of velocity due to friction against the walls. On the basis that this is equal to a layer of air 2 inches thick over the whole interior surface, and that a commercial horse-power requires the consumption on an average of 5 lb. of coal per hour, we have the following formulæ:—

$$E = \frac{0{\cdot}3\ HP}{\sqrt{h}} = A - 0{\cdot}6\sqrt{A} \quad (1) \qquad HP = 3{\cdot}33\ E\sqrt{h} \quad (2)$$

$$S = 12\sqrt{E} + 4 \quad (3) \qquad D = 13{\cdot}54\sqrt{E} + 4 \quad (4)$$

$$h = \left(\frac{0{\cdot}3HP}{E}\right)^2 \quad (5)$$

In which HP = horse-power; h = height of chimney in feet; E = effective

area, and A = actual area in square feet; S = side of square chimney, and D = diameter of round chimney, in inches.

"Another rule is the following:—

A = least internal area of flue, in inches.
a = area of grate, in feet.
HP = horse-power of boiler.
h = height, in feet, of chimney from fire-grate.
P = pounds of coal consumed per hour.

$$A = \frac{112 \text{ HP}}{\sqrt{h}} = \frac{12 \text{ F}}{\sqrt{h}} \text{ (Tredgold)}$$

F being in this case = 9·33 HP, or 9·33 lbs. per HP hour.

"A common rule is to make the flue and area of the chimney top equal to from one-eighth to one-tenth the area of the fire-grate, without taking into account the height of the chimney.

"To find the draught of a given chimney in inches of water, we have

$$d = h\left(\frac{7{\cdot}6}{t_a} - \frac{7{\cdot}9}{t_c}\right)$$

where h = height of chimney, in feet, t_a the absolute temperature of the external air = $t + 460$, and t_c the absolute temperature of the gases in the chimney = $t^1 + 460$.

"To find the height of a chimney to give a specific draught-power, expressed in inches of water, we have

$$h = \frac{d}{\dfrac{7{\cdot}6}{t_a} - \dfrac{7{\cdot}9}{t_c}}$$

"To find the maximum efficient draught for any given chimney, the heated column being 600° Fahr. and the external air 62°, multiply the height above grate in feet by ·007, and the product is the draught-power in inches of water."

Where two flues are led into one shaft, a partition wall should be erected across the shaft and carried up to double the height of the flues, so as to bend the currents in the same direction.

Average Height and Cost of Destructor Shafts.—Mr. Boulnois states that the average height of chimney is 163 feet, and that the average cost of erection is £6 3*s.* 4*d.* per foot.

Foundations for Chimney Shafts.—The foundations of a building are usually considered to include all the parts below the surface of the ground which are put in for the purpose of carrying the weight of the superstructure; the ground on which those parts are built is termed the foundation-bed.

The best foundation-bed would be an incompressible material, free from water, and of such extent and thickness that it will not yield under the pressure to which it is to be subjected; the ground to be built upon should be homogeneous.

These conditions cannot ever be absolutely fulfilled, and therefore foundations should be arranged in such a manner as to ensure the settlement, which always takes place more or less in all engineering works, being uniform.

Professor Rankine gives 2,500 to 3,500 lbs. per square foot as a safe load to be put upon a firm foundation-bed, such as hard clay, dry gravel, or clean dry sand; however, in many instances of existing buildings in London, as much as 5 tons per square foot is safely carried on gravel and on London clay.

In the case of rock the intensity of the pressure on it should not exceed at any point one-eighth the crushing strength of the rock. The following are considered safe loads for ordinary rock foundation-bed :—

TABLE 142.—SAFE LOADS FOR ORDINARY ROCK FOUNDATION-BED.

	Tons per sq. foot.
Rock moderately hard, strong as the strongest red bricks	9 0
Rock of the strength of good concrete	3 0
Rock of a very soft, crumbly nature	1 8

The bearing power of most solid rocks is, however, far in excess of any weight which in ordinary buildings can be put upon them, but great care must be exercised on rocky sites in bridging over soft dykes or fissures with concrete, as otherwise unequal settlement will occur.

Table 143, of safe maximum loads for various soils, is given by Mr. Newman in his work entitled "Earthwork Slips and Subsidences."

In order to ensure equal settlement the bearing surface on the foundation-bed should be extended until a uniform pressure, not exceeding the amount the special nature of the ground will bear, is attained.

The position of the bearing surface should be as nearly as possible perpendicular to the pressure, and the lateral escape of the supporting material or foundation-bed should be prevented.

With these objects in view, the foundation-bed should be levelled or cut into horizontal steps, and if the ground is soft it may be necessary to retain it with short piling round the site, and even to build on piles.

The nature of the ground to be built upon should be ascertained by careful examination, and by boring or sinking test-holes. The former method is not to be relied upon, as it does not afford the means of

TABLE 143.—SAFE MAXIMUM LOAD FOR VARIOUS SOILS (NEWMAN).

Description of Earth.	Approximate safe maximum load in tons per sq. foot.
Bog, morass, quicksand, peat moss, marsh land, silt	0 to 0.20
Slake and mud, hard peat turf	0 to 0.25
Soft, wet, pasty, or muddy clay and marsh clay............	0.25 to 0.33
Alluvial deposits of moderate depths in river beds, etc.........	0.20 to 0.35
NOTE.—When the river bed is rocky and the deposit firm they may safely support 0.75 ton, but not more	
Diluvial clay beds of rivers	0.35 to 1.00
Alluvial earth, loams and loamy soils (clay and 40 to 70 per cent. of sand) and clay loams (clay and about 30 per cent. of sand)	0.75 to 1.50
Damp clay	1.50 to 2.00
Loose sand in shifting river bed, the safe load increasing with depth	2.50 to 3.00
Upheaved and intermixed beds of different sound clays	3.00
Silted sand of uniform and firm character in a river bed secure from scour, and at depths below 25 feet	3.50 to 4.00
Solid clay mixed with very fine sand	4.00
NOTE.—Equal drainage and condition is especially necessary in the case of clays, as moisture may reduce them from their greatest to their least bearing capacity. When found equally and thoroughly mixed with sand and gravel their supporting power is usually increased	
Sound yellow clay containing only the normal quantity of water	4.00 to 6.00
Solid blue clay, marl and indurated marl, and firm boulder gravel and sand	5.00 to 8.00
Soft chalk, impure and argillaceous	1.00 to 1.50
Hard white chalk	2.50 to 4.00
Ordinary superficial sand beds	2.50 to 4.00
Firm sands in estuaries, bays, etc.	4.50 to 5.00
NOTE.—The best engineers consider the safe load upon clean firm [illegible] tons per square foot	
Very firm compact sand foundations at a considerable depth, not less than 20 feet, and compact sandy gravel	6.00 to 7.00
NOTE.—The sustaining power of sand increases as it approaches a firm [illegible] gravelly state.	
Firm shale protected from the weather, and clean gravel	6.00 to 8.00
Compact gravel	7.00 to 9.00
NOTE.—The relative bearing powers of gravel may be thus described: 1. Compact gravel. 2. Clean gravel. 3. Sandy gravel. 4. Clayey or loamy gravel. [illegible] gravel has been weighted with 14 tons per square foot at a depth of only 3 to 5 feet below the surface, and presented no indication of failure. The gravel was [illegible] beach.	

judging whether the soil is very compact or otherwise. Trial pits should therefore always be sunk where great weights, as in the case of a high chimney shaft, have to be supported.

Rock affords an excellent foundation-bed, especially when it occurs in horizontal layers of coarse texture, and free from crevices or large flaws; otherwise it is very treacherous and uncertain.

In order to prepare it for building on, all loose and unreliable portions should be cut away, and the hollows filled in with cement concrete; the rock may be cut into steps, which should be nearly horizontal, the outer edges having a slight inclination upwards. The lower joints of the structure resting on the steps should be set in cement, to prevent any tendency to unequal settlement.

Beds of rock lying in an inclined position, especially if there be thin layers of clay between them, are very liable to slide on each other when subjected to pressure. This may be guarded against in many places by cutting a trench across the slope of the beds of rock and filling it with concrete, so as to distribute the pressure arising from the tendency of the rock to slide downwards; the surface should also be covered with a good depth of concrete.

When it is found necessary to build upon a thin stratum of rock in preference to going through it, it will be better not to weaken it by cutting into it, but to build on its surface, giving a good spread to the footings.

Firm Earth.—The term "firm earth" includes hard dry clay, gravel, sand, etc. *It is more than ever necessary to keep the intensity of* pressure uniform in the case of foundations having to be made on hard dry clay, as it is liable to expand and contract under the varying influences of frost and wet.

A clayey soil, or even a shale rock, which is found very hard when being excavated, may become quite soft on exposure to the air; such ground should be covered in as soon as possible with a layer of concrete.

Gravel makes one of the best foundation-beds, as it affords good drainage and is unaffected by frost. It is often found in thin beds over a soft substratum; this can be discovered by trial pits

A good bed for foundations is obtainable on sand if solid, uniform, and dry; if, however, it is affected by running water it might be washed away. Where sand has to be built upon, sheeting piles should be driven in all round the foundation to prevent its lateral escape.

Piling may be considered as a convenient method for passing through a soft stratum to a hard one, so as to afford efficient support for heavy engineering works. Piling is also a powerful help in consolidating wet and soft soil to a considerable depth; the area thus consolidated should be enclosed in the first place with sheet piling, which thus affords a firm strata in opposition to the inferior one by being placed at right angles to it. The piling and the enclosed spaces together may be considered as a solid mass.

Depth.—Professor Rankine shows that, supposing the earth to have no cohesion, the weight of a building which is uniformly distributed over its base must not exceed the weight of the earth which it displaces in a greater proportion than $(1+\sin.\ \phi)^2$ to $(1-\sin.\ \phi)^2$; and further, that if the pressure of a building is not uniformly distributed over its base, as is always the case with chimneys subjected to wind pressure, the intensity of the pressure on the side where the pressure is greatest must not exceed $wx\left(\frac{1+\sin.\ \phi}{1-\sin.\ \phi}\right)^2$ and its least intensity must not fall short of wx, the intensity of the earth pressure at the same depth as that of the foundation. In this formula ϕ is the angle of repose of the soil, w its weight per cubic foot, and x the depth in feet below the surface.

The following Table, which has been compiled from Newman's "Earthwork Slips and Subsidences," gives the value of ϕ for various earths:—

TABLE 144.—VALUE OF ϕ FOR VARIOUS EARTHS.

Description of earth	*Angle of repose* ϕ	*Weight per cubic foot.*
	Degrees	lbs.
Sand, very fine and dry	33 to 27	
„ wet	26	89 to 118
Soft chalk, impure and argillaceous	32 to 26	
Vegetable earth, dry	29 to 18	
„ „ loam	33 to 26	100 to 120
„ „ very wet	17 to 14	
Clay, dry	29	
„ damp	18	120 to 135
„ sound yellow, well drained	26 to 18	
„ wet	17 to 1	
Gravel, clean and compact	45	
„ with sand	26 to 33	90 to 110
Loose shingle	35 to 39	

The minimum depth for foundations on clay in this country is four feet, on account of the action of frost, and the maximum pressure on the foundation-bed at this depth should not exceed two tons per square foot, but for every extra foot of depth this limit may be increased by one-fifth of a ton.

"The compressibility of oolitic and tertiary clays can only be overcome by piling, deep sinking, heavy ramming, or heavy weighting. *The point of bearing must be carried below the possibility of upward reaction.* The depth of a foundation in compressible ground ought not to be less than one-fourth the intended height of the building above ground—that is, for a shaft of 200 feet the foundations should be made secure to a depth of 50 feet by piling or by well sinking and concrete. Masses of concrete, brick or stone, placed on a compressible

substratum, however cramped and bound, may prove unsafe. Solidity from a considerable depth can alone be relied upon. Mere enlargement of a base may not in itself be sufficient."

Footings.—To decrease the intensity of the pressure at the base of a building and ensure its stability, footings are formed. This is done by spreading the bottom out in regular offsets, which should never exceed two and a quarter inches (*i.e.*, a quarter-brick) on each side. The depth of the footings should be at least two-thirds the thickness of the wall to be supported, and the lowest course should never be less than six inches deep. In the case of heavy structures the footings should not spread more than their depth below the surface, and it is better, if possible, to keep it within one-half the depth.

If the footings are to rest on a bed of concrete care must be taken that the maximum pressure per square foot does not exceed the compressive strength of the concrete with a factor of safety of either four or eight, depending on its being subjected to a dead or live load.

The following Table, condensed from one which appeared in the *Builder* of 19th November, 1892, gives the compressive strength of concrete in tons per square foot:—

TABLE 145.—COMPRESSIVE STRENGTH OF CONCRETE IN TONS PER SQUARE FOOT.

No	Limes and Cements.	Weight per bushel	Proportion of Lime or Cement to Gravel and Sand 1 to 6	1 to 8	1 to 10	1 to 12
		lbs	tons	tons	tons	tons.
1	Grey Lime	—	10.2	4.6	5.2	—
2	„ „ Selenitic	—	18.5	7.6	8.1	—
3	Lias Lime	—	11.4	11.1	11.5	—
4	„ „ Selenitic	—	17.2	19.6	10.2	—
5	Lias Lime	—	23.0	10.7	8.5	—
6	Selenitic Lime	—	26.6	15.3	13.5	—
7	„ Rugby Lias	—	37.1	34.2	21.1	—
8	„ Aberthaw Lime	—	34.1	21.8	15.4	—
9	Rugby Lias Cement	74	17.2	10.7	5.8	—
10	Portland Cement	114	100.7	76.4	53.5	37.1
11	„ „	120	86.4	91.7	52.2	29.1

Where a bed of concrete is laid under a building and allowed to project beyond these limits for the purpose of distributing and lessening the intensity of the pressure on the foundation-bed, it should be considered as a beam subjected to cross breaking stress, and its thickness calculated accordingly.

Table 146 on following page* gives the results of experiments on the transverse strength of concrete, and is of great service in making such calculations.

* From the *Builder*, 26 Nov. 1892.

TABLE 146.—TRANSVERSE STRENGTH OF CONCRETE AND OTHER BEAMS SUPPORTED AT ENDS.

No.	Composition: Portland Cement	Composition: Sand	Composition: Aggregate	Age in Days.	Breadth Ins	Depth Ins	Clear Span Ins	Number of Tests	Loaded at	Average Breaking Weight Cwt.	Reduced to Breaking Weight at Centre Cwt.	One-Half Weight* of Beam between Supports Cwt	Total Central Load. Cwt.	Modulus of Rupture (r) in Cwts. per Square Inch.	Average Value of (r).	Authority.
1	1	—	1 Coke breeze	7	3	5	72	1	Centre	3·85	3·85	0·31	4·16	5·99	—	A
2	1	—	2 Crushed brick	b	12	8	60	1	"	13·23	13·23	1·67	14·9	1·74	—	A
3	1	2 c		10	"	12	36	2	Central 6"	155	142·06	1·55	143·61	4·48	3·88	B
4	1	2 d		"	"	"	"	3	"	113·33	103·88	1·55	105·43	3·29		
5	1	—	4 Clean breeze	43	30	6·5	57	1	Central 16"	66·32	57·32	2·12	59·44	4·15	3·63	C
6	1	—	4 Broken brick	"	"	6	59·5	1	"	40·52	35·07	2·53	37·6	3·11		
7	1	0	5 Shingle	139	12	12	36	1	Centre	85·62	85·62	1·77	87·39	2·73	—	D
8	1	1	5 "	"	"	"	"	1	"	68·74	68·74	1·91	70·65	2·21	—	D
9	1	2	5 "	"	"	"	"	1	"	43·61	43·61	1·84	45·45	1·42	—	D
10	1	3	5 "	"	"	"	"	1	"	27	27	1·76	28·76	0·89	—	D
11	1	2	6 Gravel	90	12	12	36	3	Central 6"	46·67	42·78	"	44·54	1·39	1·39	D
12	1	2	2 Broken stone, 1½ in. / 4 " " ¾ in.	"	"	"	"	3	"	52·5	48·12	"	49·88	1·56		
13	1	2	6 " " 1½ in.	"	"	"	"	3	"	40·83	37·43	"	39·19	1·22		
14	1	0	9 Shingle	95	12	12	18	1	Centre	83·06	83·06	·77	83·83	1·31	1·27	D
							36	1	"	38·33	38·33	1·53	39·86	1·24		
15	1	1	8 "	"	"	"	18	1	"	71·18	71·18	0·92	72·10	1·12	1·18	D
							36	1	"	38·33	38·33	1·84	40·17	1·25		
16	1	2	7 "	"	"	"	18	1	"	56·16	56·16	0·94	57·10	0·89	0·94	D
							36	1	"	30·15	30·15	1·88	32·03	1·00		
17	1	3	6 "	"	"	"	18	1	"	30·28	30·28	0·93	31·21	0·49	0·58	D
							36	1	"	20·04	20·04	1·86	21·90	0·68		
18	1	3	6 " (screened)	28	21	9	99	1	Central 6"	5	4·85	6·57	11·42	1·00	0·92	E
							45	1	Central 12"	20·88	18·35	3·08	21·43	0·85		
							45 e	1	"	13·6 e	11·92	"	15	0·59 e		
19	1	4	5 "	95	12	12	18	1	Centre	24·91	24·91	·84	25·75	0·40	0·59	D
20	1	4	5 "	180	12	12	36	1	"	23·71	23·71	1·69	25·4	0·79		
21	1†	1	½ Gravel (¾ inch) / 3 Broken stone (1 inch to 4 inch)	182	6	12	36	1	Central 12"	72	66·05	·75	66·8	4·17	—	F
22	1‡	1		100	2	2	4	2	Centre	5·22	5·22	a	5·22	3·91	—	G

NOTES TO TABLE.

* The weight of the beam itself is part of the load, and must therefore be considered in the calculations, otherwise grossly inaccurate results would sometimes be obtained; e.g., the weight of the first beam of the three numbered 18 is nearly three times as much as the load put upon the beam. The weight of the beam must really be considered as a distributed load, and as the stress of a distributed load is only one half that of a central load, one-half the weight of the beam is given in the column

† Slag cement. ‡ Roman cement. a Weight too small to be considered. b Presumably seven days; the various ages of the beams should be carefully noted.

c Coarse sand. d Fine sand. e Part of a larger beam which fell before it had properly set, and was, therefore, probably strained.

AUTHORITIES.—A David Kirkaldy. B John Kyle. C Col. Crozier. D Darnton Hutton. E C. Colson. F Wm. Kidd. G Q. A. Gillmore.

Wind Pressure.*—It has been found by experiment that when a thin plate as in the case of an anemometer is exposed normally to the wind, there is in addition to the direct front pressure a negative back pressure; it is the sum of these two pressures that an anemometer registers. In many cases, however, the convergence of the wind at the back of a structure is interfered with or prevented. The wall of a building, for instance, carries the front pressure only, and in such cases the pressure due to any wind velocity is only 0·6 of the anemometer pressure.

The following Table gives the results of the experiments of Mr. Smeaton and Mr. Dines with plates struck normally, involving both direct front pressure and negative back pressure.

TABLE 147.

V, *Miles per hour*	P, lbs per square foot.	
	Smeaton.	Dines.
25	3·1	2·2
50	12·5	8·8
75	28·1	19·7
100	50·0	35·0
150	112·5	78·8

The relation between wind velocity and pressure on a thin plate is given by the following formula :—

$$P = 0{\cdot}005\ V^2$$

where P is the pressure in lbs. per square foot, and V is the velocity in miles per hour.

Numerous experiments show that the wind velocity, and consequently the wind pressure, increase with the height above the ground. The results obtained by Mr. Stevenson in 1878 with strong winds blowing over a level field are that for a height of 15 feet from the ground the velocities were low and irregular even when the wind was strongest. For heights above 20 feet, the ordinates of the velocities at different levels *in every case were those of a parabola having its vertex 72 feet* below the ground level, so that

If V and v are velocities at heights H and h above the ground level,

$$V = v\sqrt{\frac{H+72}{h+72}}$$

Hence, if P and p are the pressures at these heights,

$$P = p\sqrt{\frac{H+72}{h+72}}$$

* *Vide* Lecture by Professor W. C. Unwin, F.R.S., M.I.C.E., at Chatham, in 1897.

Supposing the pressure at 50 feet is 30 lbs. per square foot, then by Mr. Stevenson's law, assuming that it may be extended to great heights, we get :—

TABLE 148.

Height above ground in feet.	Wind pressure in lbs. per square foot.
50	30
100	42
200	66
300	91

We thus see the importance of attending to wind pressure in lofty structures.

Pressure on Solid Bodies of Various Forms.—When a solid body is presented to the wind the front pressure is modified if the face of the body is not plane, and the negative or back pressure is modified if the form of the body interferes with the convergence of the air in the wake. If we put K for the ratio of the pressure on a body to the pressure on a thin plate, of area equal to its projected area on a plane normal to the wind, then we have the values of K in Table 149.

TABLE 149.

Shape of object.	K =	Wind
For a sphere	0.31	
„ cube...	0.81	Normal to face.
„ „	0.66	Parallel to diagonal of face.
„ cylinder (height = diam.) .	0.47	Normal to axis.
„ cone (height = diam. of base) ...	0.38	Parallel to base.

On a cylindrical chimney, for instance, the wind pressure would be only about one-half that on a thin plate of area equal to the projected area of the chimney.

The effect of obliquity of surface to the direction of the wind is expressed by the empirical formula of Duchemin (*vide* article on Hydraulics in the "Encyclopædia Britannica," page 518, by Professor W. C. Unwin. F.R.S., M.I.C.E.)—

If ϕ is the acute angle between the plane and the wind's direction, and P the pressure per square foot of a plane due to the same wind *striking the plane normally* ($\phi = 90°$), then for any other inclination the normal pressure per square foot is

$$N = P \frac{2 \sin. \phi}{1 + \sin.^2 \phi}$$

When a plane is oblique to the direction of the wind the pressure is greater toward the leading edge; this appears to apply to both the positive

and negative pressures. Thus in the case of a rectangular surface at an angle ϕ to the direction of the wind, the centre of pressure may be considered as situated at unequal distances, a and b, from the leading and following edges of the plane. Thus we have the following value for $\frac{a}{b}$:—

TABLE 150.

ϕ.	$\frac{a}{b}$
72°—75°	0 9
57°—60°	0 8
43°—48°	0 7
25°—29°	0 6
13°	0 5

If the oblique plane is not freely exposed, but the direction of the current of air is diverted by other planes in its vicinity, as in the case of a roof resting on a wall, then the effect of the wall is to throw up a current of air which more or less diverts the pressure from the roof; the higher the wall in proportion to the length of roof the greater is the sheltering effect produced. The effect of shelter on roofs with various inclinations is shown by the following Table, compiled from experiments made by Professor Kernot:—

TABLE 151.

Inclination of roof to horizontal.	Normal pressure on oblique plane height (l).		
	Freely exposed	Sheltered by wall of height = $1\frac{1}{2} l$	Sheltered by wall of height 0 5 l.
60°	95	55	75
45°	87	25	55
30°	72	10	14
20°	54	0	0

The pressure on a vertical surface equal to the roof area being 100

As regards wind pressure on bridges, the Board of Trade Committee of 1881 recommended that a factor of safety of 4 should be adopted in fixing the limiting stresses; and as regards mere overturning of the bridge by wind pressure, they considered a factor of safety of 2 sufficient.

Chimney Shaft, Southampton Destructor Works.—The shaft is constructed of circular brickwork 100 feet in height from the ground line, inside diameter at the top 6 feet, ditto at the bottom 7 feet, constructed upon a pedestal 14 feet 6 inches square and 24 feet in

height, of brickwork 3 feet thick, then in 4 sections as follows (*vide* Fig. 494):—

1st in 27-in. brickwork...	... ...	30 feet high.
2nd in $22\frac{1}{2}$-in. „	... ...	30 „
3rd in 18-in. „	... ...	38 „
4th in 14-in. „	... ...	38 „

"The first thirty feet is fire-brick lined, with a cavity of four and a half inches behind, ventilated to the outer side. The lining is steadied by header firebricks, which project sufficiently to touch the common brickwork.

"The foundation is loamy clay, upon which is laid a bed of concrete thirty feet square and ten feet thick.

"The footings commence at 23 feet 2 inches square, and step off in regular courses up to 15 feet square, at a height of 6 feet. The concrete was filled in continuously until completion. The pedestal was then run up and allowed to remain for nearly three months during the winter, after which the works proceeded until completion, which occupied about six months.

"The cap is white brick in cement, with a string course about twenty feet below the top, also set in cement; the remainder of the shaft is built in mortar. This applies also to the footings. No cramps were used in the cap.

"Foot irons are built inside in a winding lead to the top.

"The shaft is provided with a copper tape lightning conductor, with inch rod and crow's-foot seven feet above the cap. The tape is about 215 feet long, the end being carried into a well.

"In August, 1888, the shaft was damaged by lightning, but was easily repaired, owing to the provision of the foot irons referred to. At this time the shaft was plumbed and found to be quite vertical. The fires were only damped down during the repairs, which occupied about eight days. With the exception of this interval they have been constantly burning for nearly four years."

Chimney Shaft—Stability of.—It is usual to design a chimney shaft in the first place, and then calculate its stability, which should be independent of the strength of the mortar with which it is constructed. The only external force to be dealt with is the wind-pressure, and this is generally taken at 50 lbs. to the foot super, which should be ample for the British Isles; but in the case of very lofty chimneys in exposed situations the increase of pressure with height above the ground level, as pointed out by Professor Unwin at p. 851, *ante*, should certainly be kept in view. It is very probable that the excessive rocking of some tall chimneys is due to this point having been overlooked in their design.

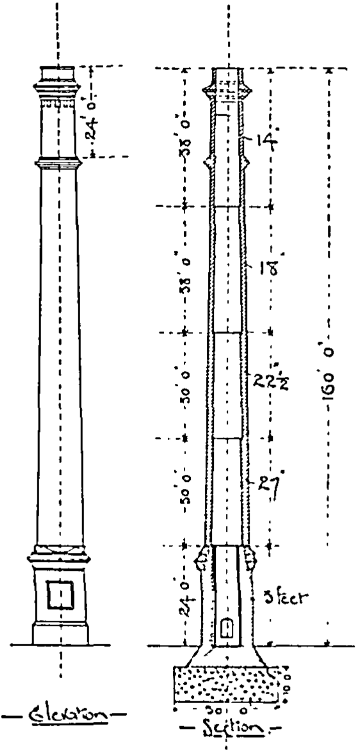


Fig. [illegible]—Chimney Shaft, [illegible]

The first step is to ascertain the weight of the shaft on the joint of maximum compression, which is found generally either at the ground-level or on the top of the pedestal, if there be one.

The moment of Inertia of the joint at this level is required, and for a circular shaft $= \frac{\pi}{4}(r^4 - r_1^4)$, where r and r_1 are the radii of the outer and inner faces of the shaft.

Thus if $p =$ the actual force of the wind in lbs. per square foot,

$S =$ area of diametral plane,

$h =$ height of chimney above the joint in feet,

the moment of wind-pressure for a *circular* chimney $= M = S \times \frac{p}{2} \times \frac{h}{2} \times \frac{1}{2240}$ foot-tons.

Here the centre of pressure is taken at one-half the height of the chimney, which is above the centre of gravity of the diametral plane; but according to Stevenson's law the centre of pressure, especially in exposed positions, would be found at some distance still higher above the ground level.

The area of the cross section of the joint under consideration is $A = \pi(r^2 - r_1^2)$ for a circular joint, and $A = D^2 - d^2$ for a rectangular cross section.

By substituting the appropriate values thus obtained in the following equation, and making $y = o$, we get the value of p.

$$y = \frac{N}{A} - \frac{M \times l}{2I} = o$$

where

y = minimum compression per unit of area.

N = total normal pressure on the joint.

A = the area of the cross section of joint.

l = the maximum width of the joint.

I = the moment of Inertia of the cross section.

The maximum pressure at this joint $= 2\frac{N}{A}$, and must not exceed in intensity the safe working stress of the materials.

If the joint thus tested is on top of a pedestal, the calculations should be repeated, after making the necessary changes, at the ground level; the stability at each decrease of thickness of brickwork in the shaft should then be tested in the same way.

To ascertain the maximum pressure on the foundations, we must find the position of the centre of pressure at the base of the shaft.

According to Rankine, the approximate positions for centres of pressure, under the condition *that the pressure decreases uniformly from a maximum at one edge to nothing at the opposite edge*, are situated, for a hollow square factory chimney, at a distance of $\frac{1}{6}t$ to $\frac{1}{3}t$ from the edge of maximum compression, and in the case of a circular ring $\frac{1}{4}t$; these positions are, however, only correct for thin rings. A more accurate determination is afforded by Captain C. F. Close, R.E., *vide* page 326, "The Principles of Structural Design," by Major Scott-Moncrieff, R.E., where if q = the distance of centre of pressure from the windward edge, then for a circular cross section where D and d are the outer and inner diameters, we have

$$q=\frac{5D^2+d^2}{8D}.$$

Similarly for a square section, where D and d are the lengths of the outer and inner sides,

$$q=\frac{4D^2+d^2}{6D}.$$

If now we compound the total weight of the shaft, acting through the centre of pressure thus found, first with the weight of the footings and then these two together with that of the concrete base, we obtain the position of the centre of pressure on the foundation-bed.

The above operation may be effected either graphically, or by taking moments about the outer edge of the shaft or foundation-bed respectively.

The following formula gives the maximum pressure on the foundation-bed (*vide* page 355, "Instruction in Construction," by Major-General Wray, C.M.G., R.E.) :—

$$Y=\frac{2N}{t}\left(2-\frac{3d}{t}\right)$$

where

N = total normal pressure on the bed.

t = length of the concrete bed in the direction of maximum pressure.

d = minimum distance of the centre of pressure as previously found from the outer edge of the joint.

The value of Y thus found should be within the bearing capacity of the soil; *vide* Table 143, p. 846.

As regards the cross breaking strength of the concrete bed it is best to consider the offsets of the footings as elastic, for it is not to be supposed that the extremity of the footings can bear as much as the portion close to the outer edge of the superincumbent masonry; if then

we take it as *nil* at the point and increasing to the mean normal pressure at the thickest point, the centre of pressure for the offset will be at a distance outwards of one-half its breadth The moment of flexure should therefore be taken about this point, the upward pressure being the mean pressure on the projection beyond the centre of the footings multiplied by the distance of its centre of pressure from the centre of the footings.

Example.—To inquire into the stability of the chimney in Fig. 493, p. 855. Taking the brickwork at 112 lbs. to the foot cube, we get from the top downwards :—

	Tons.
Weight, 1st section	58·65
„ 2nd „	67·15
„ 3rd „	75·47
„ 4th „	113·98
Weight of shaft	315·25
Pedestal	232·21
Carried forward	547·46

	Tons.	Tons
Brought forward		547·46
Firebrick lining at 150 lbs. to ft. cu.	17·37	
Footings	110·90	
		128·27
		675·73
Concrete base at 131 lbs to ft. cu.		526·33
Earth supported		170·46
Total weight on foundation-bed		1372·52

If S=area of diametral plane of chimney above joint to be examined, in this case the foot of the pedestal:

$N=547{\cdot}46$ tons.

$S=1484{\cdot}6+24\times 14'\ 6''=1484{\cdot}6+348=1832{\cdot}6$ square feet.

$M=S\times\frac{p}{2}\times\frac{h}{2}$ foot lbs. $=32{\cdot}7\times p$ (foot-tons).

Assuming the pedestal to be square inside as well as outside

$A=14'\ 6''^2-8'\ 6''^2=138$ square feet.

$t=14{\cdot}5$ feet.

$I=\frac{1}{12}(D^4-d^4)=\frac{1}{12}(14'\ 6''^4-8'\ 6''^4)=3248{\cdot}75$ (feet),

then

$$y=\frac{N}{A}-\frac{Mt}{2I}=\frac{547{\cdot}46}{138}-\frac{32{\cdot}7\times p\times 14{\cdot}5}{2\times 3248{\cdot}75}=0.$$

As there is now no tension on windward side,

$\therefore p=54{\cdot}36$ lbs. per square foot,

which is ample.

Maximum pressure on this joint$=2\frac{N}{A}=7{\cdot}934$ tons per square foot,

$=123{\cdot}4$ lbs. per square inch,

which is well within the crushing strength of good stock brickwork in lias lime mortar, taken at 400 lbs. per square inch.

Similar calculations might be made at each joint where an alteration in thickness of masonry occurs.

Foundations.—To ascertain position of centre of pressure :—

$q=\frac{4D^2+d^2}{6D}=\frac{4\times 14{\cdot}5^2+8{\cdot}5^2}{6\times 14{\cdot}5}=8{\cdot}83$ feet, and is thus situated at a point 1·58 feet from centre line. Compounding the weight through this point with that of the footings, we get by taking moments :

$$q_1\times 675{\cdot}73=547{\cdot}46\times 8{\cdot}83+128{\cdot}27\times 7{\cdot}25$$

$$\therefore\ q_1=\frac{4834{\cdot}1+929{\cdot}96}{675{\cdot}73}=8{\cdot}5286$$

or 1·2786 feet from the centre line.

Compounding these two weights with the concrete bed, earth-filling, and brick-lining :

$$q_2\times 1372{\cdot}52=675{\cdot}73\times 16{\cdot}2786+696{\cdot}79\times 15$$

$$\therefore\ q_2=\frac{11000+10452}{1372{\cdot}52}=15{\cdot}63\text{ feet}$$

and minimum distance from outer edge $=30-15{\cdot}63=14{\cdot}37$ feet.

The maximum pressure is obtained as follows :—

$$Y=2\frac{N}{l}\left(2-\frac{3d}{l}\right)=\frac{2\times 1372{\cdot}52}{30}\left(2-\frac{3\times 14{\cdot}37}{30}\right)$$

$$=51{\cdot}5\text{ tons on outer edge}$$

$$\therefore\ \text{Pressure per square foot}=\frac{51{\cdot}5}{30}=3{\cdot}4\text{ tons.}$$

This is perfectly safe, as the bearing strength of gravel is from 6 to 8 tons per square foot (Table 143, p. 846).

To ascertain whether the thickness of the concrete bed is sufficient, it is necessary to find centre of pressure on projecting portion from centre of footings :—

Half-width of footings $=\frac{23'\,2''-15'}{4}=2'\,1''$

Length of projection $=15-(7'\,6''+2'\,1'')=5'\,5''$

Pressure at centre of footings in excess of normal pressure $=\frac{9'\,7''}{15}\times\frac{\cdot1847}{2}=\cdot05902$ cwts.

Total pressure at this point $=\frac{\cdot1847}{2}+\cdot05902=\cdot15132$

Distance of centre of pressure of projection from centre of footings $=\frac{\cdot1847}{\cdot15132+\cdot1847}\times 5'\,5''=35{\cdot}71$ ins.

and $M = (\cdot 1513 \times \cdot 1847) \times 35\cdot 71 \times 5' \, 5''$

$$\therefore \frac{rbd^2}{6} = 1 \times \qquad \cdot 336 \times 35\cdot 71 \times 65$$

$$\therefore d^2 = \frac{24 \times \cdot 336 \times 35\cdot 71 \times 65}{1\cdot 39} \text{ (as } b = 1)$$

[$r = 1\cdot 39$ for concrete, 1 Portland cement, 2 sand, 6 gravel, *vide* Table 146, p. 850.]

$\therefore d = 115\cdot 9$ inches $= 9\cdot 6$ feet.

The depth of the foundations in this case is one-tenth the height of the shaft.

Cost of Chimneys.—The cost depends upon the nature of the foundations, materials of construction, dimensions, and design.

It is therefore only possible to give a very approximate idea, but brick chimneys ranging from 100 feet to 170 feet in height usually cost from £1 to £5 per foot in height.

APPENDIX I.

TRADE EFFLUENTS.

Composition of Trade Effluents.—The following extracts from a report by W. Naylor, F.C.S., A.M.I.C.E., to the Ribble Joint Committee, describe in detail the composition of some of the trade effluents met with in that district.

Bleaching Cotton.

"The object of the calico bleacher is to remove as much of the foreign and objectionable matter from the woven fabric as possible. This consists of the natural resinous, fatty, waxy colouring and albuminous matter and the artificial matter introduced in the sizing of the warps, as well as adventitious dust, dirt, and grease.

"The nature of weaver's size varies in different mills, some sizes being subject to patent law. The composition of a common size, without loading, is given by O'Neil as follows:—1 cwt. of potato starch, 6 lbs. of tallow, 6 lbs. of soap, 1 lb. of sulphate of copper: the woven fabric to contain 5 per cent. dry.

"A loading is often added which may bring the percentage of size to even thirty, though calico printers as a rule work with pieces containing less than this amount.

"Assuming the calico to contain only 5 per cent., then, when 10,000 lbs. weight of cloth is put into the kiers, a bleacher has to deal with 30 lbs. of tallow, fatty salt of copper equal to 15 lbs. of tallow, and 448 lbs. of starch, or nearly 5 cwt. as the lowest total.

"The process of bleaching, though differing in almost every mill according to the market supplied or as to whether it be for dyeing or printing only, is in Lancashire mills substantially as follows:—

1. The pieces are washed to remove loose dirt and to soften the starch, etc. (steeping).
2. Boiled in milk of lime to decompose waxy, greasy, and resinous matters as well as soluble soaps into insoluble soaps.
3. Washed. Some weavers' starch lost.
4. Passed through a sour of weak acid. Lime soaps converted into

fatty acids and salts of calcium. Any lime left in cloth is dissolved, as are also any metals in size.

5. Washed.

6. Boiled in resinate of soda or alkaline substitute. Fatty acids dissolved. Vegetable brown colours loosened.

7. Washed.

8. *Passed through chlorine solution or "chemic."* Colouring matter bleached.

9. Washed (sometimes omitted).

10. Soured again in weak acid.

11. Washed for final cleansing.

"In order to note exactly the extent of pollution caused by each of these steps in the process of bleaching, samples were obtained through the kindness of Mr. Wood, from Brinscall Bleach and Print Works in January, 1893, which gave results as follow :—

TABLE 152.

SERIES A.—BLEACHING PROCESS AT WOOD'S, BRINSCALL.

Number of Sample	Date	Nature of Sample	Parts per 100,000							Parts per 100.		Relative Volumes.
			Dissolved Solids		Total Dissolved Solids	Suspended Solids.		Total Suspended Solids	Total Solids	Acidity. Normal NaHO required	Alkalinity. Normal H_2SO_4 required.	
			Mineral	Organic		Mineral	Organic					
												Galls.
103	23rd, 24th, 25th, 26th, and 27th of Jan., 1893	Water Supply from Reservoir	8·0	10·3	18·3	*Nil*	*Nil*	*Nil*	18·3	Neutral		—
104		First Wash (or Steep), I	42·9	145·1	188·0	16·4	55·9	72·3	260·3	·2	—	20,000
105		Spent Lime from Keir, II	134·3	613·8	748·1	4·0	110·0	114·0	862·1	—	1·4	1,600
106		Wash out of Lime Keir, III	22·8	25·7	48·5	6·8	9·7	16·5	65·0	—	·3	20,000
107		First (or Grey) Sour, IV	288·9	131·4	420·3	8·8	55·9	64·7	485·0	32·7	—	1,600
108		Wash out of Grey Sour, V	42·7	22·0	64·7	3·4	10·7	14·1	78·8	1·5	—	20,000
109		Spent Ash Liquor (Soda), VI	802·1	556·4	1358·5	Taken with dissolved Solids.			1358·5	—	10·1	1,400
110		Wash out of Ash Keir, VII	30·7	20·2	50·9	3·0	9·0	12·0	62·9	—	2·0	20,000
111		Spent Chemic, VIII	114·3	29·8	144·1	8·6	11·5	20·1	164·2	—	·3	1,600
112		Second (or White) Sour, X	126·5	47·5	174·0	1·2	7·1	8·3	182·3	10·0	—	1,600
113		Wash out of White Sour, XI	8·2	12·1	20·3	2·9	11·2	14·1	34·4	·3	—	20,000

"In this series of analyses it will be noticed that the bulk of the solids lie in—

TABLE 153.

Series A1	Organic Solids	Inorganic Solids.	Total Solids	Relative Volume.	Product of Relative Volume and Total Solids
				Galls	
The First Steep	201 0	59 3	260 3	20,000	5,206,000
Spent Lime from Keir	718·8	143 3	862 1	1,600	1,379,360
Grey Sour......	187·3	297 7	485 0	1,600	776,000
Spent Ash	556 4	802 1	1,358 5	1,400	1,901,900

"The sum of the relative volumes of these liquors compared with the whole volume of waste is as 1 to 4.

"If the relative volume of the water used in any particular step of the process be multiplied by the total solids, the product will, of course, be the relative amount of solids carried out into the river by the water used in this step of the process. (To convert parts per 100,000 to grains per gallon, multiply by ·7.)

"Estimated in this manner, the total solids contained in these four (Series A1) together, are to the total solids in the whole of the water turned out as 9 to 14.

"Since then these liquors forementioned (A1) constitute only one-fourth of the whole, but contain nine-fourteenths of the solids, the question arises as to whether it should not be made compulsory to treat these liquors at least, and the option given as to whether the others be treated or not.

"It follows, too, that the remaining liquors amount to three-fourths of the whole, but only contain five-fourteenths of the total solids

"It should also be pointed out that the ratio of organic to inorganic matter in the forementioned A1, is as 16·5 to 13, and in the remaining six as 21 to 37, which indicates greater liability to decompose in the series A1.

"The remaining six alluded to are —

TABLE 154

—	Organic Solids	Inorganic Solids	Total Solids	Relative Volume	Product of Relative Volume and Total Solids
				Galls	
Wash out of Lime Keir	[illegible]	[illegible]	62	[illegible]	[illegible]
Wash out of Grey Sour	32·7	46·1	[illegible]	[illegible]	[illegible]
Wash out of Ash Keir	[illegible]	33·7	[illegible]	[illegible]	[illegible]
Spent "Chemic"	41·3	[illegible]	164·2	[illegible]	[illegible]
White Sour	54·6	127·7	182·3	[illegible]	[illegible]
Wash out of White Sour	23·3	11·1	34·4	[illegible]	[illegible]

"After those liquors referred to as being the worst, come the "Spent Chemic" and "White Sour" in order of contaminating tendency; and

as the relative volume of these two is but 3,700, they would be advantageously classed with the first four as requiring treatment.

"The process of bleaching is essentially a process of washing, and the objectionable matter washed out is moie liable to decomposition than appears at first sight.

"Professor Hummel (Djeing and Calico Printing) speaks on this subject as follows :—

'In bleach works the refuse liquids consist of alkaline and soapy solutions, together with such as contain calcium chloride, traces of bleaching powder, and free acids. Here are all the elements necessary to mutual purification, if allowed to mix together in due proportions ; the calcium will piecipitate the soap solutions, while the free acids will neutralise and precipitate the alkaline liquids and decompose the waste solutions of bleaching powder.'

"The following analyses of bleach liquor indicate its putrescent natuie, though it will be noticed the organic nitrogen is small in quantity.

TABLE 135.

SERIES B.—ANALYSES OF AVERAGE BLEACH WASTE SHOWING ORGANIC MATTER

Number of Sample	Date	Nature of Sample	Parts per 100,000								
			Total Solids	Free Ammonia	Nitrogen as Nitrites and Nitrates	Chlorine *	Organic Carbon	Organic Nitrogen	$\frac{C}{N}$	Inorganic Nitrogen	Total Nitrogen
120	9th Feb., 1893	Samples of waste bleach liquor taken every three hours and mixed (Whalley Abbey Print Co.)	186·0	012	0	10	1 45	056	26 to 1	009	065
117	3rd Feb., 1893	Samples (coloured†) of waste bleach liquor taken half hourly and mixed (Grafton & Co., Accrington.)	86 1	03	1	40	9 03	87	10 to 1	125	995
123	10th Feb., 1893	Samples of waste bleach liquor taken half hourly and mixed (Stanning s, Leyland.)	136 5	24	0	130	26·124	2 734	9 to 1	·19	2 924

* Due principally to acids † Coloured by "back pieces"

NOTE.—The above samples and all to follow were accepted from manufacturers as *bonâ fide* specimens of waste, but can only be strictly considered as such for the time defined

DYEING AND CALICO PRINTING.

Dyeing.

"Dyeing is briefly the process of passing fabrics through solutions of colouring matter, under conditions favourable either to the temporary or permanent retention of the colouring matter by the fabric. Theie are many colours which, though not readily absorbed by the fabric itself,

salep, shellac in borax, sugar, wheat flour, wheat starch, zinc chloride, and zinc nitrate. (Gardner.)

"The 'whites' or pieces to be printed are run between the plain and engraved cylinders, together with blankets and 'back pieces' or 'back greys,' which in due course become themselves smeared or coloured, and upon being washed and bleached give a colouration to the bleach waste.

TABLE 157.

SERIES D.—ANALYSES OF AVERAGE DYE AND CALICO PRINT WASTE, SHOWING ORGANIC MATTER.

Number of Sample	Date.	Nature of Sample	Total Solids.	Free Ammonia	Nitrogen as Nitrates and Nitrites	Chlorine.*	Organic Carbon.	Organic Nitrogen.	N/C	Inorganic Nitrogen	Total Nitrogen.
118	3rd Feb, 1893	Sample of waste dye (aniline) and thickening (Grafton & Co, Accrington)	204 3	·27	0	30	6·58	·329	20 to 1	22	·549
130	10th Feb, 1893.	Samples of dye waste (aniline), Stanning's, Leyland	220 0	·36	1 2	37	33 71	3 09	11 to 1	1·49	4 58

* Due principally to acids

"*It will be seen from these analyses (Tables 156 and 157) that the* character of dyers' refuse is almost as objectionable as it appears. The colour itself, however, is very difficult to obliterate entirely, though this can be done with proper appliances. A small quantity of colour will give a very decided tint to a large volume of water, the amount left in the dye becks to be thrown away being only that which remains unabsorbed after it has been worked until its value is less than the cost of running the machinery. The chances of its being removed in the becks at any time are small, for since these are heated by steam in contact with the liquor, which steam is continually condensing, the volume of dye liquor is continually increased, and the strength decreased accordingly, and the weaker the strength of the liquor the longer the time required for a given piece of fabric to abstract the colour. An excess of colour is always added too, otherwise processes which now require hours would require months. The thought of abstracting all dye in the dye-house must therefore be dismissed until mordants are discovered which will take up all the colour from solution, and that quickly.

PAPER MANUFACTURE.

"The basis of all papers is vegetable fibre or cellulose, and the object of the paper-maker to divest vegetable growth, esparto grass, linen cuttings, cotton rags, rye-grass, hemp bagging, straw, tarpaulin; ropes, peat, etc., from any other matters associated with this fibre or cellulose.

Such associated matters are resins, gums, silicious coatings, fats, oils, and very largely adventitious dirt.

"The process is briefly :—

1. Dusting and picking—refuse solid.

2. Boiling raw stuff with caustic soda, to saponify fats, vegetable oils, and resins—soda recovered.

3. Washing raw stuff after boiling with caustic soda, now termed half-stuff—soda recovered.

4. Breaking up half-stuff to pulp and washing in breaking engine—effluent wash water goes to river.

5. Bleaching the washed and broken half-stuff in poacher (or by means of chlorine gas)—bleach liquor used over again if chlorine is not all liberated, otherwise goes to river.

6. Beating bleached stuff to a pulp by means of beating engines, and washing further—effluent goes to river.

7. Passing pulp (after sizing, colouring, and loading) through paper-making machine in which it is strained, layered, rolled, and cut, emerging as paper—water from paper machine used over again continually.

"In examining the effluents from these processes the spent soda (2 and 3) may be left for the present as it may and ought to be recovered, except perhaps in the cases of mills making brown or shop papers exclusively, where only a small quantity is used. Effluents from 5 and 7, it will be seen, are used over and over again, thus leaving only the wash waters from breaking engines (4) and beating engines (6) to be dealt with, as that from 1 is solid.

"The effluents (4 and 6) are always more or less foul, depending upon the material in hand and, of course, the particular point of time in the washing process, the machines running generally about one or two hours.

"Samples of machine effluents were taken from Messrs. Dimmock's, Darwen, their natures being depicted below :—

TABLE 158

SERIES II.—ANALYSES SHOWING SOLIDS IN PAPER MILL WASH—PARTS PER 100,000.

Number.	Date.	Nature of Sample	Dissolved Solids		Total Dissolved Solids	Suspended Solids		Total Suspended Solids	Total Solids
			Mineral	Organic.		Mineral.	Organic		
160	9th Mar., 1893	Samples from beating and washing machines taken every five minutes and mixed.	152·2	110·5	262·7	32·1	63·9	96·0	358·7
161	9th Mar., 1893.	Samples from breaking and washing machines taken every five minutes and mixed.	18·6	18·3	36·9	8·1	29·8	37·9	74·8

Tanning.

"The refuse from tanneries is of a highly offensive character, due to the animal matter it contains from the washing and soaking of skins.

"Beside considerable quantities of ammonia, old limes contain tyrosin, leucin or amidocaproic acid and some caproic acid, the disagreeable goaty odour of which is very obvious on acidifying an old lime liquor with sulphuric acid, by which considerable quantities of a partially altered gelatin are at the same time precipitated. Very old limes, especially in hot weather, often contain active bacteria, which may be seen in the microscope under a good $\frac{1}{4}$-inch objective. Their presence is always an indication that putrefaction is going forward. . . . It is probable that in many tanneries the ammonia would pay for recovery from the lime liquors, which would be easily done by steaming the old limes in suitable vessels, and condensing the ammoniacal vapours in dilute sulphuric acid. (Some appliances suitable for this purpose are described in the Journal of the Soc. of Chem. Industry, III., 630.)"

H. R. Proctor, F.C.S., on Tanning.

Soap.

"Common soap is a combination of alkali and fatty acid.

"The soap-boiler boils alkali and neutral fat—*not fatty acid.* A neutral fat consists of a fatty acid in combination with glycerin. When, therefore, a neutral fat is boiled with an alkali soap is formed, by the combination of alkali and fatty acid, while the glycerin is left in the mother liquor.

"In order to effect the readier separation of soap from the mother liquor common salt is added. This mother liquor may contain, according as to whether white or black soda ash used—

"Glycerin, common salt, sulpho-cyanides, cyanides, sulphides, albuminous, resinous, fatty, colouring, and other organic matter. On a large scale the glycerin is recovered, but it is not at present in the smaller soap factories. The number of these in the Ribble basin supplying soap to the print mills and cotton mills for size is very considerable, the effluents therefrom being, to say the least, most abominable.

"For making the cheaper class of soaps dirty raw materials are often used, the dirt from which, for the most part, enters the river with the mother liquor.

"From soap factories there issue as refuse waters the mother liquors (*unterlaugen*, lit. under lyes) which remain at the salting of the curd, and which contain in the main common salt, glycerin solution, with generally a small quantity of caustic soda, the exact quantity of which

has already been fixed by the economy of the factory management. A soap factory which produces daily 500 kilos. of curd soap, supplies about 2 cubic metres of lyes as refuse which may contain from 5 to 20 per cent. common salt." (Fleck, 12th and 13th reports of the "Chemischer Centralshelle zu Dresden.")

"Sample of mother liquor entering Hyndburn Brook from H. Bury, jun., and Co., Church, 10/3/93, No. 162 :—

Organic matter ...	6,232·0	parts per 100,000,	or 6·2	per cent.
Mineral matter ...	8,810·0	" "	or 8·8	"
Total solids	15,042·0	" "	or 15	"
Caustic soda	120·0	" "	or ·12	"
Glycerin............	1,009·0	" "	or 1	"
Fat................	6,984·0	" "	or 6·9	"
Chlorine, equal to common salt ...	5,302·0	" "	or 5·3	"

"A fatty scum often arises from the soap pans in emptying mother liquor, which is skimmed into a tank and allowed to drain.

"Sample of such drainage from H. Bury, jun., and Co., Church, 2/3/93, No. 163 :—

Organic matter	242·0	parts per 100,000.
Mineral matter	532·0	" "
Total solids	774·0	" "
Fatty anhydrides	1,272·0	" "

TALLOW, MACHINE OIL, WAGGON GREASE, ETC.

"Suet, tripe cuttings, slaughterhouse offal, and other substances containing fat are boiled with acid, when the fatty acids rise to the surface, leaving below a very foul liquor for an effluent.

"Sample from Bridge, Baron, and Co., Church, 10/3/93, No. 164 :—

Mineral matter	1,682·0	parts per 100,000.
Organic matter	4,514·0	" "
Total solids	6,196·0	" "
Acidity	12	parts per 100 Normal Soda required.
Fatty anhydrides	1,166·0	parts per 100,000.

"Effluents from three last-named processes should be freed from any unused fat, soda, or acid in working, and afterwards treated by precipitation and filtration."

APPENDIX II.

SEWAGE FUNGUS.

THE presence of sewage fungus in a stream or channel is an unfailing indication of sewage contamination, and its presence in any quantity in the neighbourhood of a sewage outfall may be taken as conclusive evidence that the liquid being discharged there is not thoroughly purified.

No scientific description of this fungus was published in this country until the Second Report of the Royal Commission on Sewage Disposal, 1898, was issued. In this volume in the Report on the investigation of the River Severn by Professor Boyce and Doctors Grunbaum, MacConkey, and Hill, the following information is given :—*

"The 'fungus' is a gelatinous, cottonwool-like, and wavy, white or reddish growth, which is found in shallow water, covering stones, lining drain-pipes, or attached to water plants and débris ; we have also found it in abundance in a urinal. It is an unmistakable indicator of sewage contamination, and quantities of it are often to be seen in the streams of sewage farms, and in the small brooks and drains highly charged with sewage which are found in the vicinity of houses and villages in the country. In company with the Commissioners we first saw it at Dewsbury in the mouth of the main effluent from the sewage farm. In this case the effluent was very bright, the tufts of the fungus were very long, and of a rusty colour, owing to a deposit of oxide of iron. This form of the fungus we subsequently identified as *Leptomitus lacteus*. Later at Birmingham we encountered great quantities of fungus in the stream receiving the various effluents from the sewage farm. So serious had the growth become at Birmingham that it had been found necessary to remove it by means of screens in order to prevent it from passing into the river, where it would have produced a nuisance by setting up 'secondary decomposition.' That it was capable of doing so was amply demonstrated by that which had already been screened out, and which had been formed into a heap ; decomposition had taken place when we saw it, the odour was very offensive, and the red colour

* The description with the accompanying illustrations is published with the permission of the Controller of His Majesty's Stationery Office.

of the oxide of iron, so characteristic of the living fungus, had given place to the black colour of the sulphide. In Germany, whilst inspecting one of the large sewage farms at Berlin, we observed 'fungus' adhering to the débris in the small effluents, and we were informed that it had been a source of trouble to a bathing establishment situated in the river into which the collected effluents flowed. Subsequent inquiry by the authorities led to the conclusion that in this case no importance could be attached to its presence. There is no doubt, however, that owing to the gelatinous, bulky, and easily decomposable nature of the fungus, and the readiness with which it becomes detached, it may become one of the chief causes of 'secondary decomposition' in small rivers and streams which receive sewage.

"In the Atcham Brook, where we first found the 'fungus' in connection with the Severn experiments, the growth was white, the tufts wavy and very gelatinous, and the brook almost completely choked by it. We could not at first account for its presence, for we were unable to see any source of contamination; bacteriological examination showed that the stream contained large numbers of the *B. coli*, viz., 19,000 per c.c., and therefore that it must be receiving sewage, and probably close at hand. This surmise proved correct, for we traced the stream to a connection with the sewer of the Atcham workhouse, a building which was hidden from sight from the river, the other feeder of the stream was apparently a pure water spring; the combination of clear running oxygenated water with sewage seems to be necessary for the development of the fungus. We did not observe the fungus passing into the Severn in any large quantity, nor do we think that under any circumstance it could lead to 'secondary decomposition' in the river; the volume and velocity and the conditions of growth precluded this. In no part of the river, except in this stream, did we find the fungus, and this is not to be wondered at, considering the very great dilution which we have shown to take place in the sewage of Shrewsbury when it passes into the river. The variety of fungus found in the Atcham Brook proved to be *Sphaerotilus natans*. We have had the opportunity of studying this variety for a very long period in the River Alt, a small stream which receives the effluents from the West Derby Sewage Farm. In this river the growth forms characteristic tufts attached to the stones of the bed of the river. It is readily detached, and is liable to form accumulations and to assist secondary decomposition.

"Classed under the heading of 'sewage fungus' are certain distinct growths, the most highly organised of which is the Leptomitus, one of the Saprolegniaceæ, and, therefore, comparatively high in the scale of fungi. Next to it comes the Sphaerotilus, which may be placed amongst the more highly developed forms of bacteria. There are also

various bacterial Zooglea masses, which may assume a branching appearance and simulate a sewage fungus. One of the most interesting observations which we made during our investigations of these most useful fungi was that in polluted brooks all the appearance of the typical fungus was sometimes caused by extensive growths of a protozoon, the *Carchesium lachmanni.* In the following brief description of the Leptomitus, Sphaerotilus, and Zooglea masses, it will be seen that each variety indicates a different degree of contamination.

Leptomitus Lacteus (Agardh).

"This oomycete belongs to the family of the Saprolegniaceæ. It is very soft, almost gelatinous, and may form white, rusty, or black masses. The white appearance is the natural colour of the growing filaments, but very soon this colour is replaced by a deposit on the hyphæ of oxide of iron. The rusty colour of the fungus is very characteristic, and is an indication that the stream in which it is found is well oxygenated. If the oxygen is absorbed, as in the interior of masses of the growth, or in stagnant water, sulphide of iron is formed, and the fungus assumes a black colour, and undergoes putrefactive decomposition.

"Microscopic examination shows that it consists of long branching filaments, which are constricted at regular intervals; the branches bud off below the constrictions, and each segment has a very characteristic refractile nucleus. Zoospores are formed in the terminal segments.

Sphaerotilus Natans.

"This organism belongs to the Schizomycetes, and may be readily confounded with the preceding. It forms quite as long wavy masses as does Leptomitus. It is, however, usually white and cotton wool-like when seen in the water. It is much more gelatinous than Leptomitus. On stones in shallow streams, or coating the sides of drain-pipes, it forms low velvety or feather-like growths. Like Leptomitus, it requires oxygen, and grows best in shallow watercourses and where there is plenty of movement. Its presence indicates much greater pollution than does the former organism, and therefore it is of importance to be able to distinguish the two forms. In two cases where bacterial analyses were made of the water in which both forms of 'fungus' were found, that in which Leptomitus occurred contained at least less than 100 *B. coli* per c.c., whilst that in which Sphaerotilus was found (viz., Atcham Brook) contained over 10,000 *B. coli* per c.c. With the introduction of the bacterial bed method of treatment this organism has also made its appearance. In one case, where in the method of treatment the

bacterial filter is warmed, we found that the Sphaerotilus has made its appearance in large quantity, the conditions—circulation, aeration, presence of H_2S and warmth—being most favourable to its development.

"It is, therefore, an organism which may cause blocking of aerobic contact beds, and from these may find its way into effluents.

"Sphaerotilus has been long confounded with Beggiatoa. It is allied to the Leptothrix forms. As the microscopic preparations show, it occurs in chains of short bacilli, or as long undivided filaments. It is, therefore, much more minute than Leptomitus. This is readily seen from the photomicrographs, which are equally magnified. The filaments and rods are surrounded with a gelatinous capsule.

"A very great interest and importance may attach to this organism, if as Winogradsky has pointed out H_2S is essential to the life of Beggiatoa, and if this organism is the same as the Sphaerotilus. This fact would account for its presence in sewage. But, as pointed out above, it does not grow in crude sewage, although there is plenty of H_2S; this is owing to the absence of the oxygen, which is necessary in order to enable the protoplasm of the cells to take up the sulphur. Its presence, therefore, indicates an oxygenated sewage polluted water, and it is in this class of water in which we have ourselves always found it.

Zooglea Masses.

"In crude undiluted sewage a skin-like growth may form at the sides of the conduit in contact with the air, or at those points where crude sewage passes over a 'lip.' The growth, which has a coarse velvety appearance, consists of club-shaped zooglea masses of bacilli, and it seems probable that this bacterium, if not identical with Sphaerotilus, is closely allied to it. We found it in the very polluted drains entering the Severn.

"From observations at Leeds in connection with septic tank there appears strong evidence that the zooglea masses tend to form considerable quantities of sulphur from the dissolved sulphuretted hydrogen. Like the Sphaerotilus and Leptomitus they flourish best where the stream of sewage is most active and thinnest. This occurs in the case of the septic tanks at Leeds, where the effluent passes over the lip.

"The *Sphaerotilus natans* can be regarded as peculiar to sewage contaminated water; we are not aware of its growing under any other circumstances. The Leptomitus thrives best in slightly polluted water, and there is no reason to think it may grow to even a slight extent in clean water. The *Carchesium lachmanni* is a protozoon which we have found in great masses under similar conditions to those of the Sphaerotilus. In our experience in no other conditions does it attain to such a luxuriant growth. Like, therefore, the sewage fungus it plays no

unimportant part in sewage purification. Green algae may also develop to an enormous extent in sewage-polluted water; when they do so they may be taken as sewage indicators just in the same way as Sphaerotilus, Leptomitus, and Carchesium. In polluted land drains we have observed great growths of the Flagellate, *Euglena viridis*, and most recently Dr. MacGowan has sent us a sample which filled an effluent derived from a coke bed. Similarly Professor Letts has drawn attention to an Ulva in Belfast Loch associated with sewage contamination. Certain products of organic decomposition in the sewage appear to favour the growth of these chlorophyll forms as it does the non-chlorophyll group, and as will be seen in subsequent paragraphs there is evidence that green algae may play a most important and direct share in purifying organically-polluted water. When large masses of these green algae perish they give rise, like the sewage fungi, to very objectionable smells."

APPENDIX III.

LOCAL GOVERNMENT BOARD REQUIREMENTS
WITH RESPECT TO
SEWERAGE AND SEWAGE DISPOSAL.

(*Revised*, 1909.)

AFTER the foregoing pages were printed, but before the work was actually published, the Local Government Board were understood to have adopted revised requirements for sewerage and sewage purification schemes embodying the recommendations contained in the Fifth Report of the Royal Commission on Sewage Disposal.

It is understood that these requirements are supplementary to those given on pp. 772 *et seq.* so far as they are not antagonistic, and like the old requirements they must be regarded as being of an elastic nature and each case must be separately considered and dealt with on its merits.

SEWERAGE SYSTEMS.

"Separate" systems should only be adopted in cases where the surface water can be discharged by separate drains without creating a nuisance and where a "combined" system would be unduly costly.

STORM OVERFLOWS.

Storm overflows on sewers should as far as is reasonably practicable be avoided, but where they are necessary they should be placed in such positions and with the weirs so fixed that no nuisance is likely to result. In any district where there is an active river authority the Board will desire to be informed of the opinion of such authority in respect of any proposed overflows. In the absence of any special circumstances overflow weirs should be fixed so as not to come into operation until the flow exceeds six times that of the average dry-weather flow.

There should be no overflow for untreated sewage or stormwater at or near the disposal works.

SCREENS.

All liquid delivered at the disposal works should as a rule be passed through a screening chamber.

STORMWATER TREATMENT.

A weir set at three times the dry-weather flow should be placed *below the screens*, and any volume passing over this weir should be dealt with in storm tanks. The tanks should be two or more in number and their total capacity should not be less than a quarter of the dry-weather flow. They should be so arranged that when they are full they will act as "continuous flow" tanks, and that they can be readily emptied and kept empty when no liquid is passing into them.

The liquor from the tanks can be discharged without further treatment except in special cases, and the sludge should be dealt with by any of the usual methods which may be most suitable in the particular circumstances.

In cases where a sufficient area of suitable land is available for the purpose, detritus tanks followed by irrigation may be substituted for the storm tanks.

SEWAGE TREATMENT.

Detritus Tanks.—There should be two or more detritus tanks below the screening chamber. The capacity of each tank should be about $\frac{1}{100}$th of the dry-weather flow.

Septic Tanks.—Septic tanks should not be less than two in number, and their total capacity should be about equal to the dry-weather flow.

Chemical Precipitation Tanks.—For *quiescent* treatment there should not be less than eight tanks, each of which should have a capacity equal to about two hours' dry-weather flow.

For *continuous flow* treatment there should not be less than two tanks, with a total capacity of at least eight hours' dry-weather flow, and in most cases a greater number of tanks will be desirable.

Settling Tanks.—For *quiescent* treatment—same as chemical precipitation tanks.

For *continuous flow* treatment there should not be less than two tanks with a total capacity of from ten to fifteen hours' dry-weather flow.

Filters.—In determining the sizes of percolating filters and contact beds, the Board have, in order to allow for the strength of the sewage

to be treated, adopted the divisions into "strong," "average," and "weak" sewages recommended by the Royal Commission.

The strength of sewage should, when possible, be ascertained by analysing average samples of crude sewage taken in dry weather at frequent and regular intervals throughout seven days, and in proportion to the flow. Possibly, in the case of small works, the period for taking samples for analysis might be somewhat shorter, but the period should not be less than forty-eight hours, and Saturday and Sunday should be avoided. In every case, the daily rainfall during the period when the samples were being taken and during the seven preceding days should be ascertained.

The analysis should in all cases include the following items :—

In parts per 100,000 by weight.

(1) Ammoniacal nitrogen.
(2) Albuminoid nitrogen.
(3) Total nitrogen.
(4) Oxygen absorbed from strong permanganate in three minutes at 80 degrees Fahr.
(5) Oxygen absorbed from strong permanganate in four hours at 80 degrees Fahr.
(6) Suspended solids.
(7) Soluble solids.
(8) Chlorine.

It is also desirable that the amount of dissolved oxygen taken up during the oxidation of the ammoniacal and organic matter of the sewage should be given.

The results of analysis would of course require to be properly interpreted; but as a rough guide, it may be taken that from the figure for "Oxygen absorbed from strong permanganate in four hours at 80 degrees Fahr." the strength of the sewage may be very roughly classified as follows :—

"Strong" sewage	.. ..	17 to 25 parts per 100,000
"Average" ,,	... ...	10 to 12 ,, ,,
"Weak" ,,	.. ..	7 to 8 ,, ,,

In cases where the sewage cannot be analysed its strength should be estimated according to the water consumption, the flow per head, the kind of sewerage system, whether water-closets are in general use, the volume and nature of trade waste, the amount of dilution by subsoil or surface water, etc.

Failing satisfactory evidence to the contrary it will be desirable to

assume that the sewage is "strong" for the purpose of estimating the required capacity for the disposal works.

For the purpose of showing *the minimum total cubic contents of filters* required for treating three times the dry-weather flow in different cases, the Tables Nos. 159 and 160, on pp. 878, 879, have been prepared on the data given in the Commission's Report. Wherever possible, the figures are calculated from the data on pp. 117 and 118 of the Fifth Report: otherwise the calculations are based on the data in the tables between pp. 202 and 203.

The rates of filtration given by the Commission are rates which can generally be *doubled* in wet weather. Where it is proposed to deal with *three* times the dry-weather flow, the Commission say that it would *generally only* be necessary *to provide 1½ times the capacity of filter* required for the dry-weather flow (paragraph 293 of Report, p. 209). Hence the rates of filtration given by the Commission must be reduced by one-third to arrive at the basis for calculating the size of the filters for *three* times the dry-weather flow, and this reduction has been made in arriving at the figure in the Tables Nos. 159 and 160.

TABLE 159.—CONSTANTS FOR CALCULATING THE MINIMUM CUBICAL CONTENTS OF PERCOLATING FILTERS.

Preliminary treatment.	Strong sewage		Sewage of average strength.		Weak sewage.	
	Coarse or medium material.	Fine material.	Coarse or medium material	Fine material	Coarse or medium material	Fine material.
Detritus tanks	15	*	25	*	40	*
Septic tanks	45 †	*	70	*	100	100
Settlement tanks (continuous flow)	45 †	*	70	*	100	100
Settlement tanks (quiescent)	50 †	25	100	70	130	130
Precipitation tanks (continuous flow)	65	50	100	80	150	175
Precipitation tanks (quiescent).	100	65	130	130	170	200

Notes as to Filtering Material:

(a) A filter may be regarded as *coarse* if the material will not pass through a 1 inch sieve; as "*medium*" if it will pass through a 1 inch but not through a ½ inch sieve; and as "*fine*" if it will pass through a ½ inch sieve.

(b) "*Coarse*" material will be desirable in all cases where the liquid to be treated contains much suspended matter.

(c) In the cases marked *, the use of fine material would not be desirable unless the circumstances were exceptional.

† If "*medium*" sized material were used in these cases the figures should be reduced by about 10.

TABLE 160.—CONSTANTS FOR CALCULATING THE MINIMUM CUBICAL CONTENTS OF CONTACT BEDS.

Preliminary treatment.	Strong sewage.			Sewage of average strength.			Weak sewage.		
	Single contact.	Double contact.	Triple contact.	Single contact.	Double contact.	Triple contact.	Single contact.	Double contact.	Triple contact.
Detritus tanks ...	—	—	25 *	—	25	†	—	38	†
Septic tanks ...	—	—	33	—	38	†	75	66 ‡	†
Settlement tanks (continuous flow)	—	—	33	—	38	†	75 *	66 ‡	†
Settlement tanks (quiescent)	—	—	44	—	50	†	100	†	†
Precipitation tanks (continuous flow)	—	33	†	—	50	†	133 ‡	†	†
Precipitation tanks (quiescent).	—	43	†	—	66 *	†	133 ‡	†	†

Notes:

(a) The beds should not be less than 2 feet 6 inches nor more than 6 feet in depth.

(b) The different series of beds, in double and triple contacts, should have equal cubic contents, failing any evidence to the contrary.

(c) Where a blank is left in the tables the particular treatment indicated would only be desirable in exceptional circumstances, as the method would not generally be economical.

(d) In the cases marked thus †, the particular treatment indicated would only be necessary in exceptional circumstances (*e g*, where an unusually good effluent is required).

(e) Where three times the d.w f has to be dealt with in wet weather the indi-

thus *.

In order to ascertain the minimum total cubic contents of the filters required, divide the dry-weather flow by the *appropriate figure* (having regard to the strength of the sewage and the kind of treatment proposed) in the Tables Nos. 159 and 160, and the result will be the number of cubic yards which the filters should contain for treating up to three times the dry-weather flow, thus :—

Example I. A "strong" sewage is to be treated by means of "*septic tanks*" and "*percolating filters,*" of "*coarse*" material, and the dry-weather flow is 90,000 gallons—the appropriate figure in Table No. 159 is 45—then 90,000 gallons ÷ 45 = 2,000 : the minimum total number of cubic yards which the filters should contain.

Example II. An "average" sewage is to be dealt with by means of "*quiescent settlement tanks*" and "*double contact beds*" and the dry-weather flow is 50,000 gallons—the appropriate figure in Table No. 160

is 50—then $50{,}000 \div 50 = 1{,}000$: the minimum total number of cubic yards which the filters should contain; and as in most cases the two series of beds would have the same cubic contents, there would be 500 cubic yards in the "primary" beds and an equal number in the "secondary" beds.

The definitions of the different classes of sewage and filtering materials must be regarded as being of an elastic nature, and it may sometimes be found desirable to use intermediate figures between those given in the tables in order to ascertain the required cubic contents of the filters.

In cases where a sufficient area * of suitable land is used for irrigating the filtrate it will probably suffice if the total cubic contents of the filters is half that provided for by the tables, but where the filter capacity is so reduced it may be necessary in wet weather to restrict the flow to the filters to about $1\frac{1}{2}$ times the dry-weather flow and to pass the remainder of tank liquor direct to the land.

Effluent Tanks or Filters.—Where the effluent from filters is not irrigated on land, tanks (with a capacity equal to about two hours' dry-weather flow and with provision for removing the sludge), or shallow straining filters, will in most cases be necessary for the purpose of preventing the suspended matters in the filtrate from passing into the river.

* *Note*—Viz.: from 3,000 to 30,000 gallons (dry-weather flow) per acre per twenty-four hours according to the quality of the land.

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